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ALAN WOOD

(Authors alone are responsible for the opinions and facts stated in their respective papers, and for the accuracy of their references)

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Proceedings of the
GEOLOGISTS' ASSOCIATION

THE TEACHING OF GEOLOGY IN SCHOOLS
REPORT OF A DISCUSSION HELD ON 5th APRIL, 1946

CONTRIBUTORS

Dr. Vernon Wilson, Dr. Francis Jones, Mr. J. I. Platt, Dr. G. Van Praagh, Dr. A. E. Trueman, Miss M. E. Tomlinson, Miss M. M. Sweeting, Mr. S. G. Harries, Mr. F. E. Clegg, Mr. A. G. Lowndes, Mr. K. A. Joysey, Dr. F. J. North, Mr. H. E. Dudley, Dr. R. O. Jones, Dr. A. K. Wells, Dr. L. J. Chubb, Mr. W. B. West, Mr. H. J. W. Brown, Mr. A. H. Gunner, the President.

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The Editor, in presenting this report of the discussion, begs the indulgence of those contributors whose material does not appear. An effort has been made to present a well-arranged and readable account rather than a running commentary on the discussion itself. There is still some duplication in the views expressed, but this is necessary to allow authors full liberty to develop their arguments.

I. SHOULD GEOLOGY BE TAUGHT IN SCHOOLS?

Dr. Vernon Wilson : "Sad, indeed, is it to see how men occupy themselves with trivialities, and are indifferent to the grandest phenomena—are learnedly critical over a Greek ode, and pass by without a glance that grand epic written by the finger of God upon the strata of the Earth" (Spencer).

These words are a fitting indictment of the geological shortcomings of our present scientific education in schools. The teaching of geology in schools has, directly or indirectly, received attention in the writings of enlightened educationists and eminent scientists, especially geologists, for many years. This is the first occasion it has come before us here, and I can think of no society which, by reason of a membership drawn from people in all walks of life, is better fitted to discuss this topic than our Association. It is a great privilege for me to open this discussion and in this capacity I feel it incumbent upon me to give you a brief survey of the views and opinions which have been expressed in the past.

As early as 1867 a British Association Committee reported that a scientific training provides the best discipline in the observation and collection of facts, in the combination of inductive with deductive reasoning, and in accuracy both of thought and language. It emphasised also that such teaching must begin where it touches the pupil's past experience, which must be converted into scientific knowledge. Those observations apply very pertinently to the subject of our discussion this evening.

In 1869 T. H. Huxley¹ advocated that every child should be instructed in "a general knowledge of the earth, and what is on it, in it, and about it." Such training should be practical and "unless that which is taught is based on actual observation and familiarity with facts, it is better left alone." He maintained it was imperatively called for in the primary schools and in fact should be begun "with the dawn of intelligence."

James Geikie² has pointed out that geology, as a branch of general education, not only cultivates the faculty of clear and continuous observation, but its countless problems stimulate "that imagination which is one of the noblest gifts of our race."

Similar views were expressed by J. Logan Lobley³ before the South-Eastern Union in 1898. He stressed that the geology which should be taught "is not exactly that of the ordinary textbooks," but should be based on the natural interest of the young in things they can see and handle.

¹ T. H. Huxley, *Science and Education Essays*, London, 1925, pp. 111-133, and 160-188.

² J. Geikie, *The Aims and Method of Geological Inquiry*, Inaugural Lecture, Edinburgh, 1882, pp. 1-27.

³ J. Logan Lobley, *The Place of Geology in Education*, Proc. S.E. Union Sc. Soc., 1898, pp. 54-64.

Next, we find Lapworth¹ in 1903 putting forward the view that geology should not be introduced as a special subject of education except in the highest classes in schools. Farther on, however, we find him suggesting that the teaching of earth knowledge could begin in the elementary classes and in its earliest stages it should be simple and cover the ground familiar to daily experience.

In an address to Section C of the British Association for the Advancement of Science, Professor Watts² pointed out that "there is no science in which the materials for elementary teaching are so common, so cheap and everywhere so accessible. Nor is there any science which touches so quickly the earliest and most elementary interests" and which provides an accurate training of the mind to encounter the problems which confront us in everyday life. He concludes that in education "its rightful position should be given to a science [Geology] which is useful in training and exercising the faculty of observation and the power of reasoning, and which brings about a better knowledge and appreciation of the life and growth of the planet that we inhabit for a while."

In 1932 the then Prime Minister, Mr. J. Ramsay Macdonald, himself a former teacher, said that "if any one of the sciences were selected as the key to all the other sciences geology might be selected as that science." Surely that is a sound enough reason for the introduction of our science in some form or other to all age groups in all schools.

W. P. Winter³ in an excellent contribution to this problem has shown how geology can be taught to different age groups in elementary and higher schools and he has given us a very useful lead by listing a few selected topics which can be considered. A detailed extension of this kind of approach to the problem would, I feel, be of great service.

Our leading champion at the moment is Professor Trueman, who is with us this evening, and consequently it would be out of place for me to attempt to pick out the salient points of his contribution to the joint discussion between Sections C and L on this subject in 1937. More recently the tide of our efforts on this problem has gone forward with the pithy remarks of Professor Read to a group of parliamentarians and others in 1942 and by the reception of a Geological Society deputation at the Board of Education.

In his book on *Science Teaching*, F. W. Westaway considers it unlikely that geology will become a substantive subject of science in schools if only because of the difficulty in devising a suitable

¹ C. Lapworth, *The Relations of Geology*, Ann. Add., Q.J.G.S., 1903, vol. 59, pp. lxxvi-xcvii.

² W. W. Watts, Report of the British Association for the Advancement of Science, 1903, pp. 641-654.

³ W. P. Winter, *Geology in Schools*, Proc. Yorks. Geol. Soc., 1938, vol. 23, pp. 219-235.

course of practical work. But I note he omits to enumerate these difficulties, which are more apparent than real.

Then again, in the 1936 report of the sub-committee of the Science Masters' Association teaching geology in a general science course is not advocated "despite its obvious claims for inclusion." This attitude seems somewhat incongruous when one reads their definition of General Science as "a course of scientific study and investigation which has its roots in the common experience of children." In a similar report two years later they had evidently advanced from their original stand and some geology is included in the general science recommendations.

In the time remaining to me I would like briefly to make a few suggestions. Firstly, I agree with Huxley that the teaching of geology cannot begin too soon and many simple aspects of it can be introduced in the early years of elementary school life. Secondly, I cannot plead too strongly that any programme of instruction in geology in schools must at all times stress the pupil's experience in both the subject matter and method of science. Early everyday experiences if not rationalised into knowledge soon become evanescent as the child grows older. His restless observation should be encouraged and made as accurate and complete as possible, and only when his acquaintance with geological phenomena is becoming tolerably exhaustive should he be introduced to the new sources of information which our textbooks supply. In teaching geology we must not put theories, definitions, rules and principles first, but disclose them as they come in the order of nature through the study of examples.

The famous headmaster of Oundle, F. W. Sanderson, saw that the real problem of education was not that of creating different courses and syllabuses to suit different types, but of *reversing the process* and taking the boy himself for the starting point and trying to devise for him and those like him appropriate schemes of work. And that is what we geologists must do; we must examine our science very closely and see what aspects of it come within the common experience of all boys and girls and then devise detailed schemes of suitable topics for various age groups. This approach will necessitate much time and thought on our part, but to my mind it will be well worthwhile and in fact is the only way. And if we indicate how the various topics can be approached by the teacher then we shall save him much valuable time in devising his courses and we shall find more and more enterprising teachers introducing our subject into their school work. I recollect one evening being in an overgrown Corallian quarry just outside Scarborough when three small boys, nine to 10 years of age, entered in pursuit of moths and butterflies, and I was surprised to hear them referring to their captures by their generic and specific names. In due course they came to where I was working and seeing my fossils laid out they

proceeded to give me their full scientific names, and they followed this up by telling me of other limestone quarries where I could find different fossils from rocks of the same age. In short, they had learnt the elements of the local variations of the faunal ecology of the Corallian reefs and their associated sediments in that area. This kind of local study and instruction in zoology and botany was being actively pursued by their village schoolmaster.

I have seen town boys out of school taking great interest in the various types of granitic facings of public buildings ; Shap granite and the pale blue felspar crystals in the dark granitic rock on the front of the local public house are part of their everyday experience. What an excellent foundation upon which a teacher could build an almost complete knowledge of our igneous rocks. And why should not those elementary schoolboys see those familiar rocks in all their colourful glory under the microscope ?

Or again, think what can be accomplished starting with a piece of coal or chalk, or by discussing the geological aspects of a town's water supply. Whether in town or rural area, the observant teacher can soon find geological topics which will quickly gain the enthusiasm and rouse the imagination of all types of pupils and give them a lasting interest which will expand with experience. The school-leaving age is shortly to be extended ; now is our time to come forward with detailed geological schemes to take up some of the time of that extra year at school, though such work would be spread over the school life of the pupil. I would further suggest that such schemes should be modestly devised in the first instance for elementary and central schools, where the bogey of examinations does not loom on the child's horizon. If we begin at the bottom in this way we shall soon find geology among the subjects taught in the more advanced schools.

Dr. Francis Jones : Geology in relation to schools must be considered from several aspects : (1) As an examination subject ; (2) as a cultural subject ; (3) as a supporting subject to chemistry, biology and geography ; (4) as a science.

(1) Despite much lip service to the contrary, nearly all our secondary schools are dominated by examinations and their success is not infrequently judged by the amount of scholarship winning : so far, the freer public and semi-public schools have not succumbed to the disease, and the two older universities have laudably avoided granting scholarships solely on examination percentages. The aim of education for the majority of secondary school pupils is still very largely that of passing a general schools examination with sufficient credits to avoid a further matriculation examination, and of passing a higher school examination with sufficient marks to obtain exemptions from this and that, or to obtain one or other of the scholarships available. Geology is not a popular subject

from the examination standpoint : it carries no exemptions and few scholarships. I am not challenging examinations as such, but pointing out that they tend to canalise education.

The universities are to some extent to blame. Allowing for some elasticity in the direction of music, economics and commerce, there is an antiquated assumption that every boy and every girl that is born into their world alive shall be labelled " Arts " or " Science," and that only oddments and misfits should ever set foot in both faculties. From the point of view of geology, there is no valid reason why someone with linguistic ability should not make it part of a final degree course, except the ever-present difficulty of time-tables.

But as things are at present there is not much chance of schools adopting geology as a main subject.

(2) Geology as a cultural subject stands very high. First and foremost, it is liked. This liking commences at an early age—boys of nine and 10 take to it almost naturally. It is an outdoor subject; it involves search; it invites physical effort; it unconsciously instils a liking for the beauty of landscape and, later, an understanding of structures. It appeals at first to the collector's instinct, but the collector, unlike his philatelic counterpart, is not interested in money values or catalogued rareties, but in finding better specimens or, more thrilling still, finding something not previously discovered. At all ages we under-estimate the love of the beautiful. The elegance of a well-shaped crystal appeals to us all, whether we are geology-minded or not. This delight in the beautiful mineral, be it opal, " Blue John " or malachite, is something we cannot help. Yet it is a closed subject in our schools. Fossils too are a compound of the beautiful and the interesting. They unlock our thoughts and pose the question of time. Only the geologist has a good mental conception of time : the mathematician's fourth dimension is almost meaningless to him if he knows not the rocks and it is certainly meaningless to the multitude. In connection with time it is well to point out that geology leads to pre-history and thence to history itself. The child is fascinated by the tools and weapons of the stone-age, but how seldom does he get a chance of handling them. They are at any rate more definite than 55 B.C. or A.D. 1066 or even the Great Reform Bill.

(3) For many years I have taught chemistry and biology and know from experience that in the case of the former, and especially in inorganic chemistry, the starting point should be the naturally occurring material, the atmosphere, the sea, the mineral ore. How many chemists begin with air without relating air to the planet, or later teach the chemistry of water without a passing reference to the origin of water ? Speaking generally, the burden of chemistry is the great demand it makes on memory : there is one way of lightening the burden—to interest the student not so much in the

bottles, but in the way raw stuff is handled in order to obtain the pure material in bottles.

In biology the contact is of course via evolution. Of recent years the slow progress brought about in time is less appreciated than formerly. The examination pupil is given a few short lessons on the Mendelian theory, is packed with ideas on chromosomes and the long, though fragmentary, trail of the Geological Record is avoided.

In geography there is a wider contact and it must be emphasised that geology is the parent and in consequence no geographer should be ignorant of geology. How else can he speak authoritatively on mineral wealth, on water supply, mountains, rivers, oceans, barriers, or on the fertility of soils? If there is no geology room, then either the chemistry laboratory or the geography classroom should exhibit the raw materials.

(4) Geology is sometimes accused of not being a science or is regarded as an inferior science. It is necessary to assert that it is a major science. Science is organised knowledge based on observation, experiment and reasoning. Let us admit that experimental geology is not as strong as it ought to be, and that the subject lacks the mathematical precision of physics and chemistry. On the other hand, it demands closer and wider observation than either, and the reasoning is more exhaustive. In chemistry and physics, numerous laws restrict the field of enquiry and unconsciously the mind of the researcher is strait-jacketed. The geologist observes minutely and frames hypotheses—not one, but many—knowing full well that each must be weighed before accepting or discarding, and knowing further that he is seldom in possession of all the essential facts. One has only to think of such problems as “Flints in the Chalk”—a problem likely to be sprung on him by a child—to realise that one of the chief virtues of the science is to present possibilities, to give personal interpretations and yet to preserve honesty: such explanations as are given may not be the correct ones. It is this uncertainty which annoys those scientists who want definite answers. Geology is a science in which the question is far more important than the answer. The fundamental question occurs everywhere in the subject—“How old is this fossil?”—“Why are these rocks red?”—“Why are certain granites rich in alkalis?” and so on. The chemist and physicist, and, to a lesser extent, the biologist, take their examinations knowing all the stock answers. The geologist knows the answer current at the moment, but is still allowed to think. Apply this to the schools: in either the general or the higher examination, for the usually taken sciences the path is so well taped that an industrious candidate can get through without much original thinking: in fact, original thinking is almost original sin. The young geologist must think: he usually comes along with his problem because he has thought and is not satisfied.

Better still, when it is explained he may still not be satisfied ! The young chemist, soaked in Dalton's Laws exercised in equivalents, nurtured on Gay-Lussac and Avogadro, cannot stray from the straight and narrow way.

Some years ago the Science Experts of the Board of Education, together with some science teachers, went into labour and produced a subject called "General Science." The intention was good, but their child is mentally defective. I have helped to mark scripts in the subject for quite a number of years. The successful candidates know all or most of the answers, but are unaware of most of the problems. Geology was crowded out of this subject : it would have leavened the whole and made it worth-while. General Science at present is a compound of chemistry, physics and biology and I can say without hesitation that thinking and reasoning are the last thing it induces. Further, I am amazed at the "drill" necessary in each particular branch, especially in biology. If the child has done the drill it passes creditably : if it ventures from the orthodox path and starts exploring, it is penalised. In conclusion I advocate more geology in schools to stimulate thinking and reasoning, and judgment and tolerance for the views of others.

Although our Association is gathering strength, geology has less adherents in the ranks of the working man than in the days when education was less organised. The miner, the quarryman, the builder, the agricultural worker should know more about the earth's surface than they do. The surveyor, the civil engineer, men who are likely to go abroad in the forces or on public service, or in private enterprise ; men who undertake government, all should make acquaintance with the fundamental source of wealth—the earth's crust—but how few do ! Is not this the fault of the schools ?

Mr. J. I. Platt : In view of the extension of the school-leaving age, the time is opportune to call attention to the very inadequate and insignificant place which the teaching of geology occupies in British schools today. The position is, that the only teaching in elementary schools is of a casual nature where it may creep into the geography syllabus. There are one or two secondary schools in mining areas where a certain amount of geology is taught and some of the school examining boards include it at the School Certificate stage, and fewer still at the Higher School Certificate stage. The subject today hardly receives recognition in teachers' training colleges, and although there are schools of geology in most of our universities and university colleges, the number of students in them is small and of those prospective teachers who pass through the schools few of them proceed to the honours stage.

It is difficult to understand why the subject has failed to be recognised as one to be included in the general education of children. In one form or another it cuts across all walks of life, and even a

casual acquaintance with the subject adds so much to the fullness of living. It fosters a love of the beautiful in nature as well as a desire to preserve natural beauty and not wantonly to destroy it. It provides the means of scientific training and does not necessitate the erection and equipment of expensive laboratories. Some of the greatest of geologists have had little else in the way of equipment than a great love for the subject and a deep and burning desire to search out its truths. The initial outlay for the purchase of maps and specimens is ridiculously small when compared with the other sciences, but its value as a means of training in scientific method is quite equal to any of them. It provides excellent training in observation, in the investigation of observed facts, in the testing and proving of these facts, in the testing and applying of the inferences drawn, and in their interpretation and classification. The subject is in very essence an outdoor science and as such should have a great appeal to certain types of children, and especially in those districts which are rich in geological phenomena.

Many of the new schools will differ fundamentally from the grammar schools of today. They will have to cater for children who will become wage earners in commerce or industry. To such, a knowledge of geology will be a great asset and their fitness to take up their jobs will be increased by their knowledge of the mode of formation and occurrence and characteristics of the rocks of the country, the characters, occurrence and relative importance of such things as road metals, building stones, roofing materials, metals, fuels, cements, etc. The introduction of the subject will also acquaint the children with maps and map reading, with mining methods and simple surveying, with problems of water-supply and drainage, and by this means it may be hoped that the abyssal ignorance of the general public of today in these matters may disappear in the next generation, and, what is as important, the rising generation will have a better knowledge of the raw materials which are used and a fuller understanding of the world of nature in which it lives.

Dr. G. Van Praagh : Owing to its broad and humanising nature and to the emphasis on observation and collection, geology is an excellent subject of general education for younger schoolchildren, both dull and bright. It should permeate the teaching of several other subjects, particularly geography and chemistry ; its importance to geography is well recognised, and I find that it has the beneficial effect on chemistry of taking the subject back from the bottles of the laboratory to the mines and quarries. It forms many cross-links between the other sciences and would form an excellent backbone to a general elementary science course. In my view, these are the main contributions geology should make to education : I do not think it is a very good science for treatment as a separate subject

and for teaching the scientific method, for although it provides splendid scope for observation of facts and collection of data, its hypotheses to explain these are often not easy to grasp, and the number of experiments which can be performed to test the theories are very limited. So that it is in the first, or observational, stage that its chief value lies, and hence the emphasis placed on its position in the early part of the school curriculum.

Geology may well be studied as a post-certificate subject in preparation for a university course. After some small experience of this I am inclined to agree with Professor H. H. Read in maintaining that chemistry, physics and mathematics should remain the basic sciences taught at school to those who are preparing for a scientific career, and that further specialisation should be left to the university stage. I believe that a geologist should have had a grounding in chemistry and physics up to Higher Certificate at school, and also that other non-science subjects should continue to form part of the education at that stage. If this is to be done properly there is not really time for a third science, such as geology. However, if the student has been introduced to the subject during the first years at school he will be ready to take up its serious study on entering the university.

In considering how the Geologists' Association can foster the teaching of geology in schools, I think that, in view of the foregoing remarks, the science teacher who is not a professional geologist is most in need of help. I agree with the speaker who proposed that the Association should set up a small committee to consider what it might do in this matter, and I put forward the following suggestions for their consideration :

(i) To publish an outline schedule of geological topics suitable for teaching at various stages. As an example, chosen quite at random, I find that the chemistry of copper is greatly illuminated if a start is made by the examination of malachite, the action of heat and of dilute acid upon it, and that this greatly helps the teaching of the analogous chemistry of calcium, which again should be closely related to the natural sources of its compounds and the changes they undergo in the earth's crust as well as in the test-tube.

(ii) To increase the number of lectures for teachers given in the geological museums and the universities.

(iii) To organise an occasional Field Meeting, specially designed for teachers working in that neighbourhood.

(iv) To start a magazine, "School Geology," for the benefit of teachers of all subjects and their pupils. Each number would contain one or two articles by professional geologists, and also have plenty of space for contributions from schools describing local features of outstanding, but simple geological interest.

(v) To compile a "Locality Index" so that teachers and children, at home or on holiday, could have a simple guide to what

is to be found in a given locality, and also references to district memoirs and other works for further information. If this compilation would be too arduous a task to undertake as such, the index to the magazine suggested above ought, after a number of years, to provide the requisite guidance.

These projects will, of course, cost money, but it would be expected that the publications would pay their way and that the increase in interest in geology would result in an increased membership of the Association.

Dr. A. E. Trueman expressed his pleasure that the Geologists' Association was taking an interest in the educational aspects of geology. For a considerable period, ending about 10 years ago, many geologists had shown a great reluctance to advocate the teaching of geology in schools; having viewed the matter from the university angle they concluded that the teaching of the subject was more conveniently begun in the universities. These considerations do not apply to pupils who do not proceed to the universities. Gradually, however, with the extension of Higher School Certificate courses in other subjects, the university geology departments found themselves deprived of students and it became clear that unless a student's interests in geology were aroused before he entered the university it was unlikely, in ordinary circumstances, that he would enter that department. The British Association discussions and committee were partly an outcome of the consideration of this problem, but a much wider approach was made to the teaching of geology and he commended to the attention of the members of the Association and others the two reports which were published, in the second of which outline syllabuses for courses in schools of different types were put forward.

He believed that geology fared better in the schools, especially in the elementary schools, in the days before formal science teaching had developed, when a science lesson, or sometimes a so-called "object lesson," stirred an interest in many matters outside the limits of formal physics and chemistry. The pressure to improve science teaching had, in fact, led to a great restriction. The problem had become worse instead of better, at any rate for a time, with the great development of geography teaching. It is true that many geographers introduce a geological background, and do so most adequately. It is true also, no doubt, that many teachers of biology introduce references to fossils and to the history of rocks at some point in their teaching. It may thus be claimed that some geology is being taught. In the first place, however, it must be emphasised that the subject that is being taught is rarely called geology, and secondly, that in the main it is being taught by people who have never themselves studied geology.

For the fact remains that many geology departments of the

universities of England and Wales (Scotland may fortunately be excepted in this connection) have had comparatively few students in late years, and that the exponents of other sciences, in general, do not advise their students to take courses in geology in order to deal with those aspects of their subject with which geology comes in contact.

The relations between geology and geography are obviously closest and it has been regrettable that during roughly 20 years the geography departments in some institutions have cut themselves off to a large extent from a close association with the geology departments. This feature probably followed in part from the history of geography within the universities, but it had resulted in great numbers of geography teachers being trained with only second-hand, or third-hand, knowledge of the science with which they are greatly concerned. Present indications point to a closer co-operation between the geographers and geologists in future and this is much to be desired.

What should be done by geologists in these circumstances to extend the teaching of their subject at all levels is a question that cannot be answered shortly. Certainly it is not sufficient to produce reports or to send resolutions. Geologists must be alive to this problem and prepared to take steps to advance the subject in every possible way. There are, however, three things to which attention should be drawn.

In the first place, geologists in the universities should strive to secure degree schemes in science and in arts with a wider basis than those at present in operation in many universities. The close links between mathematics, physics and chemistry, and the desire of the biologists to secure students trained in chemistry, and increasingly in mathematics and physics also, have meant that few of their students are advised to study geology. It is essential for the good of our science, and of these sciences, that geology shall figure more prominently in the courses of students who are specialising in other subjects. Teachers must not think too exclusively of those who are to be professional geologists. It is essential that geology shall be more widely represented in degree courses amongst those who are to teach in schools if there is to be any hope of progress in the teaching.

In the second place, an interest in geology must be stimulated in schools of all types by all possible means. In some it may be appropriate to develop an interest first through scientific and field clubs, but these will not be successful from our point of view unless there are keen geologists available. They may not be able to establish geology as a full science subject in competition with chemistry or biology, for example, partly because the time-table is too crowded. It has secured such a place in a number of schools in Wales, however, and the teaching of geology in secondary schools

there is extremely successful. Geology will generally progress where science subjects are less compartmented, and in the lower forms of secondary schools, and in primary schools, geology may flourish as part of a course of general science or of geography, in the hands of capable teachers much more satisfactorily than it would as a separate subject. At the higher school certificate level the position is different. While exemptions from first year university classes are granted on the higher school certificate, and while the choice of science subjects is in most cases made in the later years at school, geology will always be neglected if it is not represented at this level in the schools.

Thirdly, it is essential that suitable books for schools should be provided, and they must be provided by geologists. There is a great need for simple geology books suitable for all stages of school reading. He thought they would best be served by books on general science, written by geologists, but giving only a fair and balanced place to geology in such a scheme. He hoped there were some members of the Association with a knowledge of what is wanted in school books who would undertake these tasks.

II. THE EXPERIENCE OF THOSE WHO HAVE TAUGHT GEOLOGY

Miss M. E. Tomlinson : My excuse for taking part in this discussion is that I have taught geology in a Co-educational Grammar School in Birmingham for three and a half years. I shall therefore limit what I have to say to a few facts about the work and a few difficulties encountered.

I have no doubt as to the great interest the subject arouses in pupils of all ages. Until four years ago no systematic geology was taught in the school. However, as a teacher of geography I found it desirable to introduce elementary geology (without using the name) as part of the geography course. Local quarries were visited and simple instruction given on types of rocks and scenic features. Usually, these excursions were voluntary and they took place out of school time. The School Scientific Society also provided a means of geological study. Keen pupils formed a geology section and lectures were given by pupils and staff. The annual excursion organised by the Society took pupils to districts farther afield like Malvern, Church Stretton, and the Cotswolds. Here the geology section, under the leadership of a member of the staff, spent the day studying the geology of the area. Some pupils became so keen that they expressed the desire to study the subject further. This became possible when the Northern Universities Examination Board, in 1943, included geology as one of the subjects which might be offered for the Higher School Certificate examination. Geology was then included in the school curriculum as a sixth-form subject.

Equipment. We have no geological laboratory. An ordinary classroom, which also serves as a geography room, is used. Although this leads to minor difficulties such as congestion and inaccessibility of material, the handicap is not overwhelming. We have been fortunate in getting together from various sources, including our own collecting, a fairly large collection of mineral and rock specimens and fossils. Professor Wills, of Birmingham University, came to our aid with the loan of geological survey maps which were difficult to obtain in war-time. He also lent us a petrological microscope. The Birmingham district provides a great variety of rocks for study in the field, ranging in age from Pre-Cambrian to Jurassic. The course, therefore, includes as many field excursions as possible. Day excursions usually take place out of school hours on Saturdays. In addition, we organise a five-six day excursion farther afield each Easter. Llangollen and the Matlock district are visited in alternate years, so that students have seen something of the geology of both these districts during the two years spent in the Higher School Certificate course. I find the students extremely keen on these excursions and feel convinced they have more value than weeks of classroom study. Of course, the groundwork must have been done in the classroom if the maximum benefit is to be obtained from the field work. So far the class has been small (four-five students each year). Two years are spent preparing for the examination, and both first and second year students take lessons the same time.

Syllabus. I need not give details of the H.S.C. syllabus. It includes most of the work usually taken in a first year university course except that students are not examined in microscopic petrology. Practical work includes exercises on geological maps and identification of common minerals, rocks and fossils. Students who take up geology for the H.S.C. need have no previous knowledge of the subject. However, most of the students have been introduced to geology in the course of their geography studies. We have submitted candidates for this examination for two years only, but already three students have gone on to the university to take an honours geology degree in preparation for making geology their career. More would have done so but for the demands of conscription.

It seems probable, therefore, that a school geology course may be a means of furnishing more pure geology students for the universities. A student usually chooses to study in the university those subjects which he has taken for his Higher Certificate. If, therefore, geology was not one of these subjects, it is unlikely that he would wish to take it up for the first time as a subject for his degree. Unless some interest in geology has been aroused in the schools, many students are unaware of the possibilities of making geology their career. Important as is the function of school geology in

providing possible students for the universities, it has an even greater value in arousing a keen interest in the countryside. One function of a school is to train pupils how to spend their leisure; and how better than in the study of geology? Pupils with a little knowledge of the subject gained in geography lessons will come back from holidays and rambles with rock specimens and fossils for identification and numerous questions are asked. If this interest can be aroused, pupils may, in later years, join Natural History Societies and Field Clubs and pursue the subject further. Thus an interest may develop which may continue through life.

One of the difficulties encountered in the school with which I am concerned is the choice of subjects which should be grouped with geology for the Higher School Certificate examination. From the point of view of the school, geography is an obvious choice since the two subjects have so much in common. Biology is also taken as the third principal subject, while chemistry is sometimes offered as a subsidiary. This grouping is not looked on favourably by the geology or mining department of the university. I think they would prefer geology to be grouped with chemistry and physics and biology to the exclusion of geography. This would be a pity, in my view, since geology and geography are so intimately connected. In some schools the difficulty might not arise if a general science course were taken to School Certificate standard. Then students would at least have been introduced to chemistry and physics and could then enlarge their knowledge of these subjects during their university years. In other schools (of which my school is one) the pupils take either chemistry and physics or biology for the School Certificate examination, so that students reaching the sixth form may be taking geology without any knowledge of chemistry or physics. If the student wishes to take a geology or mining course at the university this is a real disadvantage.

The question of careers open to pupils who take school geology is important. There seems to be little difficulty in placing the first-class man who wishes to make geology or mining his career; even the good average man can usually find a post. The girls, however, who study geology at school find it difficult to follow geology as a career, although it is undoubtedly of great value for students who intend to teach geography.

There remains the question as to what stage in the school course geology should be introduced. It has been suggested (B.A. Report, 1937) that a general science course consisting of elementary chemistry, physics, biology and geology should be taken up to school certificate standard. I think there might be some difficulty in finding a member of the staff qualified to teach all these subjects. If such a general science course were not possible, I would suggest that geology should be taught wherever possible throughout the geography course until after the School

Certificate examination has been taken. Then a systematic treatment of the subject could well begin in the Higher School Certificate geology course. In conclusion, I should like to plead for the arousing of geological interest in pupils of the modern secondary schools as well as in grammar schools and for its inclusion in teachers' training college syllabuses. There is no doubt of the great cultural value of the subject. In these days, when so many people seek to be entertained during their leisure hours, it is increasingly important that young people should realise some of the joys gained from an interest in geology. How better can this end be achieved than by the teaching of geology in schools by teachers who are themselves keen on the subject.

Miss M. M. Sweeting : As recently as last year I was teaching geology in a school where I was invited by the headmistress to start an entirely new course ; I was thus able to watch the subsequent reaction and interest in all parts of the school.

Being primarily a geographer, I originally wished to start a course in geology because I felt it would be of great benefit to pupils who were intending to read geography at the university. At first, therefore, the course was framed to fit the needs of geographers, and the geography and geology classes were run together as far as was possible. This was easy from the physiographical side, as these classes in the two subjects could be combined—a great saving from the time-table point of view, which is always a great consideration in the planning of any school curriculum. Once the course had got started, I found that others, besides intending geographers, were interested, and so this class, framed as a fairly advanced post-school certificate one, came to include girls who were later going to study agriculture, social science and other subjects. They have since said that geology was very helpful to them, in addition to the interest they found in the subject.

As a result of this interest I later ran a special "general" course for young people who were proposing to take up secretarial and other work. This was purely experimental in nature with no examination in view, and I was able to develop the course in accordance with the wishes and desires of the class, the equipment available, and that very variable quantity, the weather. In this case, as opposed to my original more advanced course, I did not set out to give the pupils any rigid geological training—but rather to suggest to them the cultural value of the subject, its immense practical applications, and the future delight they might get by following it up in their own time as a hobby. Such a course, it is obvious, can be run in the minimum of time.

Interest in the subject as a whole spread from the more senior pupils of the school to the junior members, who pressed in their geography lessons for some "snippets" they had obtained from

their senior fellows. It is obvious that the 11-14-year-olds are greatly interested, as is evidenced by their continually bringing specimens to identify. As a response to this interest we included a certain amount of elementary geology in the general science courses. In the time available, it was impossible to make the teaching very systematic and this to a certain extent detracted from its value. But there seems to be great scope for the inclusion of some elementary geology in with the "nature study" lessons which are so popular with the 10-13's in every school. They, too, can learn about the different types of rocks and the work of rivers, and they can collect—and do—to their hearts' content. As the School Certificate stage is approached the place of geology and its interest is less certain; for here the basic sciences—physics, chemistry, biology and mathematics—must take first place. Even so, geology might be included to a certain extent with a general biology course, which is now so popular.

Throughout a school, therefore, there are excellent possibilities of giving pupils some idea of what geology is, how it links up with the rest of knowledge (for children separate all subjects into rigid compartments), and what fun they can have with it. I think, if anything, it helps the pupils to visualise their history and other teaching with a greater sense of proportion. The average young person has a poor time sense—history to them does not begin more than about 2,000 years ago—and though they all know that an Ice Age has occurred, they feel it happened just before the Romans came to Britain. It is to them a revelation to realise that one million years is but a fraction of geological time. Although biology is now taught from an evolutionary point of view, to actually see and handle fossils makes that teaching far more real. Pupils do not often realise how dependent our coalmining, oil and mineral prospecting are upon the knowledge of the geologist; coal, oil and iron are, indeed, taken for granted.

Again, it is surprising how, to the pupils, most rocks look alike—yet once differences are pointed out they are very quick to recognise new types. On the physiographical side, even quite young children are interested in rivers, beaches and glaciated valleys. I was very fortunate in the situation of the school, as at my doorstep was the Vale of Clwyd and examples of many physiographical phenomena were within reach of a short walk from the school. Even if one has not much time to devote to the younger children in the way of field-work, yet they can be encouraged to keep their eyes open when they are out on their own.

With my more advanced class, field-work of quite an extensive type was done. I aimed to give the pupils at least a working knowledge of the geology of their school area. I think they benefit considerably from getting out and knowing the region in which they live; geology becomes the basis of a study of the local

environment by which their geography, natural science and history are combined. The value and interest of the subject as studied in the field cannot be over-estimated. I was indeed fortunate to be working in so excellent a neighbourhood—but I feel more could be done by contact with a local Natural History Club, which would seem to be of utmost value.

Usually at least one aspect of geology appeals greatly to the pupils. If anything the stratigraphical side appears rather more difficult (not necessarily less interesting), partly, I think, because one cannot visit the localities with which one is dealing ; but here the interest they will gain from the subject when on holiday needs stress, and those who are keen will use their knowledge of historical geology when visiting, say, an area of Cambrian or Jurassic rocks.

A great argument in favour of the introduction of geology into schools seems to me the fact that so little equipment is needed. For about £15 a good teaching set of rocks, crystals and fossils can be obtained—to which can be added the pupils' own collections. Photographs and postcards can be accumulated over a period of time. Geological maps are also important, but the apparatus and equipment required to take geology to an advanced standard in schools is very much less than that needed in any other of the sciences.

The people who took the courses I have described have all said they enjoyed them—and I think the value of the subject as an observational training compared well with the other sciences. There is no need to stress the very numerous links of geology with the other sciences and with geography in particular.

Here, perhaps, it is important to insert a warning. Schools are already complaining of an overcrowded curriculum—that there is not sufficient time to teach really well, even the subjects that are needed for entry into academic studies, or into courses for technical and secretarial work. Competition has become so keen that a high standard of academic work is being demanded for almost all types of posts. Hence many people in schools do not favour the introduction of what is to them just yet another subject. We must always remember that other subjects, like civics and economics, have their advocates for inclusion in the teaching in schools.

Recently suggestions have been made regarding the lesser degree of specialisation needed for both academic and other courses, which would limit the time given by the pupil to examination subjects and give more scope for what is called "cultural education." If this is put into practice, then both teachers and pupils should have more time to devote to non-examination subjects, and geology should find a place in the general education of not only the more technically and scientifically minded, but also for the linguist, the secretary and the nurse.

Despite these difficulties, which are very real, geology should benefit from the great opportunities afforded by the new Education

Act. If children are to stay at school longer one of the most beneficial studies they can undertake is that of their own local environment—a study of their own surroundings (what their houses are built of, etc.). This has been recently advocated by Professor Trueman in a report to the British Association. An advantage is that such a study can always be continued by the pupil in his own time and holidays and needs the minimum of equipment, and he can “potter” around with very little instruction. Such studies would seem to have most scope in connection with science lessons for younger children, 9–12 years of age, or as part of the general education given to older people after they have passed the School Certificate stage—these are the two age groups to which, I think, geology has most appeal. The collector’s instinct and the thirst for facts will appeal to the younger set, while the more philosophical aspects are not appreciated until people are considerably older.

A subject so broad and general in scope as geology should on no account be made rigid and standardised ; yet if we envisage geology playing a bigger part in the life of the community than it does at the present time, we must always bear in mind the need of supplying teachers of good standing with geological knowledge.

Mr. S. G. Harries : The following notes may be of interest. At Oundle School, in addition to the incidental geology taught at the School Certificate stage, we provide instruction on the following syllabus for boys who are on the agricultural side :—

“ Rocks and Minerals. Weathering, transport and corrosion. Sediments. Superficial deposits. Soil formation on bare rock surfaces. Influence of climate and rock type on soil formation. Modification of soils by wind transport. Formation of “ pans ” in soils. Characters and classification of soils. Soil types in the British Isles. Water Supply, drainage and irrigation. Geological maps and their use to the farmer. The geology of mineral manures.”

The practical work includes an examination of soils in the field and analysis of them in the laboratory. The soil auger is in use and soil profiles and weathering are studied in the field. Boys are required to recognise the main rock types and minerals.

Occasionally an individual boy needs more geology for professional purposes. Such are taken over the syllabus of the Oxford and Cambridge Board. The relevant part is : “ The outlines of Geology, viz., the principal igneous, aqueous, and metamorphic rocks, including recognition of specimens ; denudation ; deposition of stratified rocks ; dip, strike, joints, cleavage, faults, and dykes ; unconformable stratification ; the principles on which the relative ages of rocks are determined ; outlines of stratigraphical geology ; the recognition of the fossil genera found in the principal formations.”

The one candidate who took this course last year later secured an award at the Royal School of Mines.

Furthermore, the Geological Section of the School Geographical Society visits local pits and quarries to collect fossils and rock specimens. Several members show great interest.

Equipment.—The school is fortunate to have a student series of fossils selected by Dr. J. E. Marr, from the Woodwardian Museum, Cambridge, and presented to the school by Professor McKenny Hughes. The school supply of geological maps is, owing to war conditions, inadequate, as is the sole petrological microscope. We plan to add new microscopes and a representative collection of slides. The collection of rocks and minerals is adequate.

General. It is my wish to see more geology taught to intending civil engineers and architects. My headmaster is sympathetic to the proposal and before long I hope to have such provision at Oundle.

The Geologists' Association can serve the interests of geology in schools by encouraging the production of more suitable elementary text books. Trueman's *Introduction to Geology* is good, but would be more useful with a somewhat fuller treatment of stratigraphy and of fossils. There is a real need for a well-illustrated, non-technical book on fossil identification. Not a few boys first approach geology this way. The illustrations of fossils in the several British Regional Geology Handbooks are what I have in mind as the standard of illustration, and if such could be combined with descriptive matter in the form of the Oxford *Bird Book for the Pocket*, I feel assured that they would find a ready market.

It is further suggested that the Association consider the possibility of organising junior field meetings to provide schoolboys with an opportunity of viewing some of the classic sections. If the interest of boys could be captured by carefully planned field work, the cause of school geology would be appreciably advanced.

Mr. F. E. Clegg : A recent report of the Committee appointed by Section C of the British Association to consider the teaching of geology in schools showed that there are probably less than 20 secondary schools in England and Wales where geology is taught, even to small numbers of pupils as a full science subject¹. At a few elementary schools a certain amount is taught, but this is largely where it is inspired by personal interest of the schoolmaster concerned, or where special facilities and encouragement are afforded by a museum in the locality.

The position of geology in the curriculum may also be inferred from a study of the syllabuses issued by the main examination boards in the country. In an examination of syllabuses in 1938

¹ British Association for the Advancement of Science, 1936 and 1937 Reports. (An earlier Report, in 1867, apparently bore no fruit.)

the Central Welsh Board appeared to be the only one which included geology as a whole subject for the School Certificate examination. The amount of geology covered in the geography syllabus was negligible in all cases, but two boards included a little geology in their General Science course. In the Higher Certificate course the position was rather more favourable, and geology could be offered as a principal subject in four of the Higher School Certificate examinations.

It is unlikely that the position will have improved markedly during the war years ; indeed, the reverse is probably the case, e.g., the 1943 syllabus of the Cambridge Local Examinations showed that geology had been reduced from a possible principal subject to the subsidiary level.

The sorry state of geology in our schools requires some explanation. It is probable that geologists lost a valuable chance of introducing geology into schools when they allowed geographers to seize a branch during the great advance in geographical studies which took place soon after the 1914-18 War. It is also fairly obvious that the purely cultural value of geology is not sufficiently appreciated by teachers. This cultural aspect will be considered later. A third reason for the apparent neglect of geology is that apart from mining and oil geology, geologists as a whole appear to be little interested in the applications of their science. In this respect they are in marked contrast to the chemists and physicists. Fortunately some recent publications by Fearnside and Bulman, and by Seward,¹ show that this attitude is waning. The present shortage of geologists, which has now persisted for some time, seems to have stirred some people in this country, and resulted in the special committee set up by the British Association for the Advancement of Science to enquire into the teaching of geology in schools. It is to be hoped that this leads to a more complete realisation of the applications of geology, by all and sundry. Yet another reason may be seen in that only a very small proportion of training colleges include geology in the curriculum for the teachers' certificate, and there are very few teachers receiving training in it.

The Science Masters' Sub-Committee decided not to include any astronomy or geology in the syllabus for the General Science course, "despite their obvious claims to inclusion."² The shortage of time seems to have been the main factor in deciding this, though they also point out that geology is taught by the geographers "in a way which suffices for the purposes we have in mind." This hardly seems to be in accordance with their definition of General Science, which they say is ". . . a course of scientific study and

¹ *Geology in the Service of Man*, Fearnside and Bulman. Pelican, 1944. *Geology for Everyman*, Seward. Camb. Univ. Press, 1943.

² *Teaching of General Science* (Murray, 1936), page 34.

investigation which has its roots in the common experience of children, and does not exclude any of the fundamental sciences."¹ Why it should be supposed that one or two features of physical geology appeal to the common experience of children while the rest of geology does not is by no means clear. Their definition of General Science continues: ". . . It seeks to elucidate the general principles observable in nature without emphasising the traditional division into specialised subjects until such time as this is warranted." The very absence of geology from the general science course will surely tend to make pupils who think about it regard geology as a specialised subject, even to the extent of regarding it as being not connected with General Science. And yet it does not appear in some of the examining boards' syllabuses, although the Science Masters' Association appear to have advanced somewhat from their original stand, some geology appearing in the first two years of the General Science course which they planned in the later report.²

It has been argued that geology not being a fundamental science like physics or chemistry is unsuitable for work at the school stage, but this view ignores some important points. First, geology is a typical observational science, and is much the most easily applied of such sciences. There is no branch of science which lends itself more readily to inductive treatment, and almost every locality affords facilities for the quickening of the faculties of observation by the collection of significant facts and drawing definite conclusions from them. In addition, an intelligent interest in the nature of the crust of the earth, its phenomena and causes generally comes early, and unless this curiosity can be satisfied it tends to be lost or crowded out by other interests. A third point is that it is very important that pupils should have the opportunity of realising while they are young that there are sciences other than the so-called fundamental ones. They should have the chance to consider their attractions and the possibilities of devoting themselves to one or other of them. Its more specialised study at a later stage provides openings for those who wish to make it their profession, and it is of use to pupils taking up various types of career.

The aims of science teaching have been classed under three headings:—

- (1) Utilitarian (or vocational), i.e., as being of use to the pupil in his later life, and possibly as a means of earning a living;
- (2) Disciplinarian, or training of the mind, and
- (3) Cultural, forming a necessary part of one's social life.

The claims of geology for inclusion in the syllabus may now be examined in the light of these aims of science teaching.

¹ *Teaching of General Science* (Murray, 1936), page 30.

² *Teaching of General Science, Part II* (Murray, 1938).

The absence of mention of geology in most curricula is leading to a shortage of students which seriously threatens to affect the quality of professional geologists, and to react adversely on the teaching and research in the science. It may be contended that this does not affect the schoolmaster, since the training of experts is not his concern. The Sub-Committee of the Science Masters' Association takes a wider view, and while it points out that the preparation of experts cannot be considered as a function of the school, the pre-preparation of experts is one of the schoolmaster's tasks, for it is at school that particular talents are discovered and their development fostered.¹ The strange fact that "talent" should be an anagram of "latent" has been drawn attention to by W. P. Winter, in an excellent discussion on geology in schools, to which I am much indebted.²

At present the posts open to graduates in geology fall into four classes : mining and oil appointments ; Geological Survey posts ; museum work ; university appointments. Apart from the relatively small number of students who may eventually make geology their profession, it should be remembered that geology will be a useful subsidiary subject for students training for various types of career in agriculture, science and engineering. It is usually taken by students reading civil engineering, mining, and metallurgy, but it may be argued that some knowledge of geology, such as would be obtained by a school treatment of the subject, is of use to many other scientific workers. The majority of materials used in industry are obtained from the earth's crust, and geology has a wide range of applications to problems related to building and road materials, foundations, soils, drainage and water supply. Bearing all this in mind, and especially the rapid expansion of the oil industry in recent years, the proposal to introduce geology into the syllabus would survive the test of utilitarianism.

The second aim of science teaching—the disciplinarian aspect, was put forward at a time when the belief in the transfer of training was far stronger than it is today. The disciplinary values of a subject can now no longer be used as one of the main arguments in its favour. It would have been said at one time that geology may develop in the child a fine critical faculty owing to the discrimination of genera and species. It would also have been pointed out that the actual extraction of the fossil often demands patience and self control, and even then the best part may break, but in the light of present knowledge these cannot be given as reasons. It has been shown that the traditional view that Latin and mathematics teach people to think better than do the other subjects is not the case. Thorndike has indicated that the subjects best in this respect (though even so the transfer is small) are arithmetic

¹ *The Teaching of General Science, Part I*, page 10.

² *Proc. Yorks. Geol. Soc.*, Vol. xxiii, Part IV, page 219.

or bookkeeping, and the exact sciences ; the transfer effect of the biological sciences was very slightly negative.¹ However, the labelling and stocking of specimens promotes neatness, and this is one feature which it seems does get transferred.

The collection of fossils might also prove a means of sublimation, and cases are known where a child's general work has improved 100 per cent after he has taken up the hobby of collecting stamps or fossils. The collecting instinct is probably strongest from about 12½ to 14 years of age and the opportunities here are numerous.

Psychological experiments have shown that the sentiments which grow up around a subject are very important. "In the moral character, of all who are old enough and intelligent enough to have their mental processes systematised in this way, sentiments are by far the most potent factors. In the directing of conduct and behaviour they constitute the ruling guides and supply the main incentives. They furnish our chief aims, our chief motives, and our chief ideals, together with the vigour and enthusiasm needful for their achievement."² It is necessary, therefore, that the pupil's introduction to science should make him feel that it is a study which can be applied to things that interest him. The child is interested in his surroundings at a very early age, and will, therefore, tend to approach the work eagerly and with pleasure, for natural science is unique in its appeal to the child's enquiry. The study of animals, then plants, then geology and astronomy, would seem to be a logical order of presentation. Physics and chemistry, being more artificial, would come later. The conclusion is, therefore, that to present the subject of science to a child, one should include geology as an integral part. It will appeal to his interests, and should aid his future success, as it assists a more natural and complete initial approach to the subject of science, thus helping to build more useful sentiments.

Several interesting features appear when the subject is considered from a cultural standpoint. For any educated person, some acquaintance with the principles of geology is essential, for some of the most profound changes in thought have resulted from the growth of geological knowledge. This is especially the case as regards the history of life on the earth, for during the last century geology was able to refute the widely accepted view that the first life on the earth appeared in the year 4004 B.C. While the implication of the age of the human race and the antiquity of the world are realised by the scientific world and by educated laymen, it is probably quite true to say that the historical background of most people does not extend beyond a few thousand years. And yet the material basis of this knowledge, the problems of water

¹ Thorndike, *Mental Discipline in High School Studies*, Journal of *Experimental Psychology* XV-1 and 2 ; also XVIII-6.

² *The Young Delinquent*, Cyril Burt.

supplies, soils, and distribution of mineral wealth, which control many of our activities, are matters of daily moment. Such topics as a broad outline of the history and evolution of the earth and life on it should not then be excluded from a general education.

A strong plea for geology as a hobby is made by Seward, and he says : “. . . my chief aim is to present a case for the inclusion of an intelligent interest in geology as part of that intellectual equipment we call general culture, culture that has been defined as what remains after we have forgotten all we learnt at school.”¹

Chemistry, physics and mathematics is an artificial selection of subjects, and unfortunately it represents the science training given in a large number of schools today. The factors leading to the direction of science in schools into these three channels are described by Winter.² It cannot be said to lend itself to the cultural employment of leisure, but geology certainly does this. “It gives a meaning to every piece of country visited” (Watts) and exercises a rapid hold over the imagination when properly taught. Indeed, the interest in geology usually outlasts schooldays. It is agreed that in some sciences taught in schools, especially those with extensive subject matter, the teaching has become narrowly specialised and even dogmatic. There is a danger that at the end of his science training a pupil may have acquired a great deal of information, but may have had little chance to develop the true scientific outlook. The study of the exact sciences alone tends to produce an attitude showing lack of toleration, and geology in schools would act as another check on the exact sciences. The courses in general science which are now becoming popular are tending to even out the instruction given in the exact and inexact sciences, but even so it is doubtful whether a successful balance has been obtained.

Having seen the desirability of including geology in the school, the problem now arises as to how it should be treated. There appear to be six possible ways :—

(1) Introduce geology as a separate subject at the age of 12 or 13, physics, chemistry and biology having been begun previously as in the normal course of events. Unfortunately the headmaster is already faced with the time difficulty. If he could keep clear of external examinations then he might make several changes, but at present it seems that geology as a separate subject is almost impossible. For the School Certificate examination many pupils offer a selection of subjects such as chemistry, physics, possibly biology, mathematics, English, French, history or geography, Latin or German. The substitution of geology for one of the non-scientific subjects would give a much too scientifically biased course, and none of the scientific subjects would be easily displaced

¹ *Geology for Everyman*, page 3.

² W. P. Winter, *loc. cit.*, page 221.

by geology. An additional subject could not be taken without difficulty except by the brighter students, owing to the time difficulty, and so one is forced to the conclusion that geology as a separate subject in the School Certificate examination can be arranged only with difficulty under the present system. A discussion here of the merits and demerits of the group system would be out of place, but it seems clear that if the group system were abolished and specialisation at the School Certificate stage was permitted, then room could easily be found for geology. As a result of the steady development which has taken place in the secondary school curriculum, and the increased attention given to group IV subjects it has become evident that more elasticity is needed in the examination, and that the present requirements restrict for many pupils the opportunities for developing their interests and aptitudes. Attempts to provide this elasticity by methods of compensation have not been satisfactory. Clearly no amount of compensation can allow for a subject such as geology which has been completely crowded out of the course. It has been proposed that either the language group or the mathematics and science group may be omitted ; or that each candidate would have to pass a qualifying test in English, and to pass in five other subjects. These five subjects would be chosen from the approved list of subjects without any restrictions except those applied by the limits of the school curriculum and organisation. If either of these new systems were adopted then geology would find a place in the School Certificate course without any difficulty. But this would not be a satisfactory introduction for geology, which would thus be confined to those who had already decided to specialise on the science side. This must represent the minority even in these days of rapidly expanding science, so our problem of presenting geology to all children would still be largely unsolved. There is more to be said for :

(2) Introduce geology as a simple addition to chemistry, physics and biology in the general scientific training. Here the time difficulty does not arise in anything like so acute a manner. It has been argued that the introduction of General Science into schools would reduce the standard of attainment in one or more of the specialised sciences reached by pupils who propose to enter a university. Its opponents condemn it on the grounds that it is not a good preparation for the Higher School Certificate examination, blandly oblivious to the fact that the number of those proceeding to H.S.C. in science subjects is probably not more than 10 per cent of those entering the school. This is hardly the place to enter fully into a discussion of the pros and cons of General Science as a subject for the secondary school but assuming that this reduction in attainments would take place (though it is by no means certain), surely it is of less importance than the certainty that such a course will give to the far greater number of students, whose formal

training will end with school life, an appreciation of the scope and aims of science and illustrations of its contact with ordinary life. More specialised instruction on individual science subjects could be given to pupils who wish later to devote themselves to science, and this could be done at a later stage of school life. The division of science into separate subjects is already crumbling, especially in early stages, and it may be that the subject divisions will be further broken down. Dr. F. M. Earle envisages this in his suggestions on curricula in multilateral schools : " In the multilateral school, therefore, the break with tradition which occurs in matters of organisation and classification requires a corresponding revolution in the curriculum. Instead of classifying various activities under names such as English, arithmetic, and so on, the attempt should be made to devise other groupings." ¹ The Norwood Report also favours general science for the first stage of a science course in all schools, at least, and with some small modifications up to the School Certificate stage.²

(3) Use geology, with biology, to furnish a science for the start. Swinnerton has quoted a school in Nottinghamshire which starts science in this way, apparently with quite satisfactory results. It is later broadened by the addition of descriptive physics and chemistry, the main work in these two subjects begin left until the mathematics is of a high enough standard. This method of treating geology is really an extreme case of the general science method, which is probably to be preferred since it should give a better growth of sentiments around science as a whole, as indicated above.

(4) Under the heading of geography. Geology could be taught as the fundamental basis for geography. Now that geography is not so much a question of " Where is a town ? " as of " Why is it there ? " geology and physical geography should form its basis. This is illustrated in, for example, the teaching of the geography of Great Britain. As in the case of other countries the teaching is first regional, and then this regional treatment is followed by lessons of a more general character. The first problem is, therefore, to secure a satisfactory division of the country into regions which can be given a special treatment. So important to a country is the distribution of coalfields and of mountains and plains that any division into regions must largely rest on a geological basis, though not too rigidly, as a purely geological division would be too complicated for teaching. If geology is to be taught from the geographical point of view then it should certainly be taught by one qualified in it as well as in geography. The palaeontological side would be more subordinate, except in the case of biological students, and petrology would not be recognised in detail. This method of

¹ *The Times Educational Supplement*, 16th March, 1946.

² *Curriculum and Examinations in Secondary Schools*, 1943 (H.M.S.O.).

teaching is not to be recommended, however, as it would be very hard to do justice to both the geology and the geography, and one of them would almost certainly be neglected.

(5) As a post-school certificate course. It could be offered for the Higher School Certificate examination as a principal or as a subsidiary subject. It should also be quite useful to the non-university candidate, giving the non-specialist something definite and fresh. At this stage the Board of Education can insist that certain subjects be taken, e.g., English by science students, and science by arts students. For those who are contemplating a university career the strain of examinations may be such that there is no spare time for the study of geology as a subject in addition to their examination work. For those who go to the university a scholarship may mean much, both financially and academically. In addition, those people who regard examination results as a criterion of the school would be loth to support geology for study when it is a non-examination subject. Thus there does not seem to be room in the post-school certificate course for geology for those who are going to the university, but only for the others, and as a result there are very few who offer geology as a subject for the Higher School Certificate examination. This is a great pity, since the choice of university subjects is really decided by school subjects, and so we get many people who do not take geology at the university merely because they have not done any before and do not wish to start a new subject. This is probably due to the high standard to which work in school subjects has been carried, and to the exemptions from first-year examinations which are thereby granted at several of the universities.

Geology should also find a place in the studies of sixth formers not offering the science group, i.e., those preparing for classics, history, modern languages and mathematics. It should be possible to run a post-school certificate course in General Science which would be beneficial to both specialists in science and non-scientists. This would have a very broad basis, e.g., the social consequences of scientific advance seem particularly appropriate today, and scientific method would be well to the fore. Geology could be of great help in such a course, which is discussed in a recent volume of the "Current Problems" series.¹

(6) The introduction of geology into the primary school may be considered, since it suggests a junior course in the secondary school. Here again the elements of geology will be taken in connection with geography for the most part. The choice of subject matter for inclusion in the science course should be controlled largely by the neighbourhood. There are schools situated in areas which may be described as natural geological laboratories, and

¹ *Science and Education* by Humby and James, page 76. Cambridge University Press.

where the teaching of geology affords an obvious link with the surroundings. Thus in mining areas children should know something of the history and structure of the rocks, and of the effects on them of earth movements. In many areas the children can see how the physical nature of rocks affects scenery, soil and communications, and how their chemical composition affects the vegetation. There is no reason, however, why the teaching of geology should be confined to such areas, for it could be dealt with in urban schools, especially where a local museum makes a display of local phenomena. London schools are especially fortunate in this respect for the models, photographs and dioramas at the new Geological Museum are of such value that it can be claimed that many London schools have advantages for teaching the subject which outweigh the disadvantages arising from the distance from areas where field work can be done. It is not only in primary schools, however, that geology could effectively be taught in this way, with stress on local conditions, in fact it might well be taken the first two years at the secondary school. This could represent the absolute minimum of geology to be taught in secondary schools, and would serve as a subject which is to be dropped before reaching the School Certificate stage. There are many secondary schools which commence with a wide variety of subjects, which are reduced to seven or eight subjects during the school certificate and preceding year.

The detailed content of the syllabus at the various stages will not be given here. The topics which might reasonably constitute the geology part of the General Science course : a syllabus for the teaching of geology for the first two years of the secondary school ; a syllabus for geology as a School Certificate subject ; and details of the course for the Higher School Certificate, are all given in the British Association Report for 1937. Suggested lines for practical work are also indicated, using apparatus which is commonly used in science departments. A very important fact to recognise is that the subject matter will vary much in treatment, being based on the scenery of the school area, and on specimens collected locally.

So much for the past and the present. What of the future ? Once again after this second world war we shall see the rapid expansion of geographical studies. First-hand experience of life in other countries will stand in good stead those who enter the teaching profession from the Forces. Their teaching would be even richer, were it to give geology its rightful place in geographical work. It would be good if the examining boards could increase the number of questions dealing with geology in a geography paper, or even make a section on geology compulsory. The way in which the external examinations control the matter taught in schools need not always be so detrimental as it has been in the past. The failure of the examinations to follow the curriculum and not determine it,

in spite of considerable efforts, has recently been discussed by J. L. Brereton.¹

The use of visual aids for teaching is on the increase, though it does not seem that geology has benefited much. There are many excellent photographs of natural phenomena, taken by H.M. Geological Survey, but too seldom are these seen outside museums. Could they not be available for purchase by schools at cheap rates ; or alternatively be arranged in suitable sets (e.g., agents of erosion, evidence of glaciation, folds and faults, etc.), which could be hired for short periods ? Up to the present the teaching films that have been made include many first-class biology reels, but geology does not lend itself to film treatment so readily. A series of ecology films by Gaumont-British Equipment has one reel in each series (woodland, moorland, heathland, downland) devoted to geology, but there is room for improvement in those which I have seen. Thus in a section dealing with the weathering of rocks the splitting of rocks on a mountain side, followed by their rolling down on to a plain below was shown by an animated diagram. Here, in addition, there should surely have been given a "shot" of Wastwater Scree, or some such natural example at the present day. Similarly animated drawings showed the movements of glaciers and the ice sheets over England, but the opportunity of improving this section of the film with "shots," for example, of the classical perched blocks at Norber (Austwick), and typical U-shaped and V-shaped valleys, was not taken. The advantages gained by cinematograph treatment should not be allowed to block out the fact that these many processes belong to the present as well as the past.

The opportunities for schools and adult educational bodies to join the various associations on half-day expeditions should be made the most of. Clearly not all such outings would be suitable, but where the directors or leaders feel it could be profitable details should be sent to those who might attend. Thus the local school could be informed by details sent to the geography or science master. I have known many schoolchildren who had their interests aroused by excursions with the Hertfordshire Natural History Society. I well remember also a day field meeting of the Yorkshire Geological Society which was attended by several members of a nearby Workers' Educational Association Group. In many parts of the country the W.E.A. organise summer excursions and offers to assist in providing outings would generally be welcomed.

It would be well for all geological associations to keep in close touch with educational progress, and when they feel so inclined to submit recommendations to the appropriate authority. Thus, for instance, any publication of a geological association which would be useful in teaching, or in the training of teachers, might well be

¹ *The Case for Examinations*, J. L. Brereton. C.U.P., 1944, page 87 *et. seq.*

circularised to all the training colleges. In addition, it is to be hoped that the recently formed Council for the Promotion of Field Studies, with its first field centre just opened at Flatford Mill, in East Suffolk, will have the support of associations, and the help of their members wherever possible.

George Bernard Shaw has told us that the famous Doctor John Abernethy was wont to state that his business was that of a direction post, which points the way to a place, but does not go thither itself. This has also been said to be true of the teaching profession, but the road back to the Pre-Cambrian has been badly signposted, and had few travellers directed along it. This must be remedied, and the route become thronged with a new pilgrimage in search of those joys which when experienced make the journey well worth while, so that the pilgrim echoes with St. Bernard—"Believe me who have tried. Thou wilt find something more in woods than in books. Trees and rocks will teach what thou canst not hear from a master."

Mr. A. G. Lowndes : I do not consider that geology is in any way a suitable subject as a part of the ordinary school curriculum.

What geology is taught should be taught as a part of the science course, in other words it should not be tacked on to geography.

The Empire obviously wants some geologists, but it wants good men, in this connection it should avoid the mistake made by the biologists largely as the result of the Chelmsford Report of 1932 with the result that a great number of boys and girls started specialising in biology at school with the idea of obtaining suitable posts in the colonies. The final result was that the market very soon became over-stocked.

The older universities immediately set up large research departments which attracted vast numbers of students for whom there were no jobs with the result that most of this excess drifted back into the so-called teaching profession in our schools.

Since I think I can claim to have been the first in the market and certainly the most successful in obtaining men for the overseas Geological Survey perhaps some remarks of mine as to how I started and how I should certainly start again were I called upon to do so might be of value. I was at Marlborough at the time and a course in geology was started in response to a request from parents. I collected a few of the senior boys together and we started straight off on petrology. I provided one petrological microscope and the school eventually provided another and yet another after some years. We planned an excursion to the Isle of Arran for the summer holidays. I gave a short course of instruction first of all on optics and crystal optics and then on simple mineralogy and petrology.

We obtained the necessary maps and memoirs and read them up and finally made our excursion which proved to be remarkably successful.

I only had four boys for that excursion, three of whom went up to Cambridge and took up the subject professionally, while the fourth went to London University, specialised in geology and took his Ph.D. and then took holy orders for which he was far more fitted.

Of the other three, one won the Wiltshire Prize for mineralogy and then the Harkness for geology. He is now the Director of the Geological Survey of India. Another more or less followed him and has been for some years on the Geological Survey of India.

The third man went to Cambridge and won the Harkness Prize for geology and is now Professor of Mineralogy at Johannesburg.

Then ——— University with its usual arrogance interfered. They had no knowledge whatever of the conditions under which I had to teach the subject, of the fact that I was quite unpaid or of the fact that the subject was costing me personally some £30 per annum out of my own pocket. They tried to force me to drop petrology and teach geology as a part of physical geography.

The objections were, first, that I personally had no interest in physical geography, and, secondly, that there was a strong geographical department at Marlborough who would have been very justly annoyed at any interference on my part for I was a member of the science staff and senior biologist at that. I have never allowed ——— or any other university to dictate to me in the matter of teaching my subjects at school, and I accordingly dropped the teaching of geology altogether at Marlborough.

III. A SCHOOLBOY LOOKS AT GEOLOGY IN SCHOOLS

Mr. K. A. Joysey : During the discussion I was much impressed by the statistics given by Dr. A. K. Wells concerning the lack of honours degree geology students at London University. I believe that this is largely because so little geology is taught in schools, and unless pupils chance upon it outside school, they are not likely to hear of its existence.

I became interested in geology when my parents took me (at the age of six) to visit the caverns in Derbyshire. Observing my interest, my parents bought simple geology books for me, and I read as much as possible on the subject, and studied specimens in museums. All my holidays were spent collecting rocks and fossils of all descriptions, from Cumberland, Derbyshire, North Wales, and the Kent and Dorsetshire coasts.

Of course, I received no geological instruction at the elementary school, but I thought that when I entered the secondary school at the age of eleven, I should have the opportunity of studying the subject. However, after my first year I had to take the choice of either physics and chemistry (Science) *or* geography (Arts), and so by taking the science course I lost all opportunity of even the little

geology which might have been included with the geography course. This arrangement of subjects ruled for four years of the school course. Meanwhile, I joined the Manchester Geological Association (my family then lived in the north), attending the lectures and field meetings, and collecting fossils in Derbyshire, which Dr. Jackson of Manchester University kindly identified for me.

After I had passed the School Certificate examination my family returned to the south, and I became a member of the Geologists' Association. I determined to take geology as one of my Higher School Certificate subjects. However, I found that it was not in the school curriculum, and at first I studied mathematics instead.

After a few weeks I found that there was a geology evening class once a week at the S.W. Essex Technical College, so I now take physics, chemistry and biology at day-school, and geology at the Technical College. This necessitates having a meal out after school, waiting for the evening class to begin, having a two-hour class, and then a one-and-a-half-hours' journey home—where I arrive after 10 p.m. My headmaster also allows me periods at school for private study in the subject, and supplies text-books, but, of course, I can get no help or tuition between the classes.

In the Higher School Certificate examination last year I obtained a "good" in geology, but unfortunately did not obtain a full pass in the other subjects. I am taking the examination again this year, and hope eventually to enter London University.

So, although I have been able at last to take geology, it has been with great difficulty, much of which could have been avoided if geology had been introduced more generally into our educational system, and if there had been no ban on taking geography with the science course in my secondary school.

The manner in which the Geologists' Association can help is to try to arouse the interest of teachers in geology, and so induce them to introduce it into parts of the geography, chemistry and biology courses.

Much could be done by producing a small journal consisting of papers by experts, teachers and students themselves, and by so doing bringing geology before the eyes of the schools.

IV. THE CO-OPERATION OF MUSEUMS WITH SCHOOLS IN TEACHING GEOLOGY

Dr. F. J. North : Ever since the National Museum of Wales became a working institution after the 1914-18 war, its geological department has maintained the closest possible contact with schools with a view to stimulating interest in geology. The activities have included lectures and demonstrations in schools and in the museum, the provision of facilities for students to make use of material in the museum, the loan of lantern slides, and the loan or gift of

specimens. Students from training colleges have been specially encouraged because of the opportunity provided for stimulating an appreciation of geology in potential teachers, many of whom will go to elementary schools.

Even during the war, when some of these activities have been curtailed, they have resulted in contact with about 800 pupils and 30 teachers in a year.

The impression gained from these contacts (which have been shared by the writer and his colleague, W. E. Howarth) is that one reason for a reluctance to introduce geology into secondary schools is the tendency to over-emphasise the economic aspects of the subject. Hitherto, compared with subjects like chemistry and physics, geology has offered too small a number of posts for it to be thought worth while to spend time in its study, when the syllabus is already so crowded with lessons on what are regarded as "career" subjects.

This view of geology must be replaced by a realisation of its place as a cultural subject, and its value as a background in studies of geography, the history and processes of industry, and even of chemistry and physics. These matters are very little appreciated by education authorities in general, with the result that the introduction of geology directly or indirectly in school usually depends upon the ability and enthusiasm of the individual teacher. A more general adoption of geology in schools will, the writer suggests, only result from a wider public appreciation of what geology stands for.

Experience shows that there is no better way of creating popular interest and stimulating popular liking for geology than through the medium of museum exhibits, when they have been wisely planned and suitably installed. At present, however, only fairly large museums, which are comparatively few in number, have facilities for dealing with a subject like geology, and steps should be taken to make it possible for attractive and informative geological exhibits to be made accessible, even in small museums, where no trained geologist is available on the staff. This involves a new popular assessment of the support which should be given to museums.

Other desiderata include well written and well illustrated books dealing with various aspects of geology and its relation to other subjects, and emphasising the part it can play in broadening the mental horizon. Such books must be written by those who know the child-mind. It is not sufficient merely to express adult conceptions in "simple" language.

For use in schools there should be large reproductions (say, 24in. x 18in., or 18in. x 12in.), including some in colours, of photographs or paintings of features of geological interest or of scenery with an obvious geological "story," with brief and boldly printed captions.

The tendency to absorb certain aspects of geology into school geography often leads to an unsatisfactory presentation of the former and should be discouraged. Matters pertaining to geology should be indicated as such, and recognised as having been "borrowed" in order to make geography more intelligible.

Education authorities should be encouraged to give facilities for the establishment of school museums and to foster collaboration with museum curators likely to be able to help. The scarcity or absence of teaching specimens has been stressed by many teachers, and in the National Museum of Wales it is the practice for geological specimens, typical of their kind but not required for the collections, to be set aside, and lent or given to teachers (in Wales) who come and select what they can use.

To sum up, if the teaching of geology in schools is to be extended with useful results, popular interest in the subject must be aroused, and educational authorities must be made to realise the cultural value of knowledge concerning the structure and history of the earth. The subject must be presented to children as one which will add to their interest in life in relation to places they will see and things they will use, and that may in certain circumstances offer itself as a career.

Mr. H. E. Dudley : Scunthorpe, in North-west Lincolnshire, is a workaday town situated upon the Frodingham ironstone, which is quarried very extensively to supply the needs of the several large iron and steel works which comprise the largest local industry. As the greater part of the youth of the town and neighbourhood gravitates into the quarries and ironworks, it is the practical and commercial aspect of geology which appears to present the greatest appeal to the minds of these young folk. Local students who take up the study of geology for its own sake are few and far between, a fact which has to be remembered when planning talks in the museum.

"The Rocks upon which we Live" has formed an attractive and suggestive title for a first talk, for the lads respond to the suggestion that they not only dwell upon the ironstone (or near to it) but derive their sustenance from it, and, finding that the subject has a practical side, they appear to decide that, after all, geology is not going to be as dry as they thought it might be. Accordingly, the whole of this initial talk is devoted to the Frodingham ironstone, including a description of the conditions under which the beds were formed, together with corroborative evidence provided by typical fossils, which are handled and examined by the boys. The ironstone wagons are followed on their journey from the quarries to the blast furnaces and pig-iron beds, the imaginary tour being then continued to the steel furnaces and rolling mills, and mention is made of the many uses of the various by-products, all of which, it is emphasised,

owe their origin to the rocks so abundant in this neighbourhood. The scholars are allowed to examine specimens of British and foreign iron ores, samples of various grades of pig-iron and of finished steel sections, all of which have been presented by local works.

In the following talk (or talks) is given a simple review of the successive local formations from the Trias of the Isle of Axholme, in the west, to the Chalk of the Lincolnshire Wolds, in the east, together with their common fossils, and special reference is made to such branches of economic geology as building stones, clays, cements and water supply.

The curator of a museum is at some disadvantage in determining the possible value of such geological instruction, for, when the talks are concluded, the classes come no more. But it is encouraging to note that museum talks are almost invariably followed by visits from boys asking for information about the fossils they have found in nearby quarries or other exposures, and a few such scholars, now young men, have retained their interest and often visit the museum ; some exhibit small fossils gathered on foreign service. Incidentally, some of the finest local specimens in the museum have been brought by young ironstone workers who attended the talks during their schooldays. So, although one cannot follow the seed when once it is sown, a few green shoots are springing up, and may, in time, produce a worth-while harvest.

Dr. R. O. Jones : At the Geological Museum there are excellent models of the Weald, London Basin, Isle of Wight, etc., and these models are invaluable in enabling children to think in three dimensions and to link up the solid geology with the topographical features ; the dioramas are also excellent for linking up the geology with scenery. The handling of specimens by the children is very helpful and, of course, short lantern lectures followed by demonstrations are popular with children. Prior to the closure of the museum on the outbreak of war schools were making full use of the facilities as preparation for school journeys and as part of the General Science course. Technical institutes also availed themselves of the facilities for studying building stones, minerals, etc.

The Education Officer of the London County Council asked for a series of lectures and demonstrations to be given at the Museum for L.C.C. teachers during the session 1938-39. This course was so well attended that arrangements had been made, prior to the outbreak of the war, for two series of lectures to be given in the session 1939-40. The teachers attending the course in 1938-39 were very keen indeed to get a general knowledge of the principles of geology in order to bring it into their teaching and in order to make full use of school journeys.

The Education Authorities and the teachers, therefore, appeared to be fully aware of the importance of teaching some geology in the schools and he considered that the important thing was to see that geology should be taught in the training colleges so that the teachers were qualified to give instructions in the subject. Teachers who had this knowledge and were interested in geology would always be able to bring in a great deal of the principles of the subject into their teaching.

Although it was not possible in London to take children to see interesting exposures in the immediate neighbourhood, an occasional trip to Whipsnade or Box Hill would often kindle their interest and cause them to ask questions on the general geology. He had found, at the Geological Museum, that children who had been away on holidays or had been to school camp would bring back hand-specimens and photographs and ask for explanations. The interest in this direction had grown so much that when the Museum was closed in 1939 arrangements were being made for holding informal meetings on Saturday mornings for school children when they could bring along their specimens and it had been hoped that the children themselves would get sufficiently interested to give talks of their own to other children ; in other words, to have a young geologists' club meeting every Saturday morning in the Museum lecture room.

V. TWO CONTRASTED OPINIONS FROM THE UNIVERSITIES

Dr. A. K. Wells thought it as well that those engaged in teaching and in preparing young people for the university should know what is happening within the universities. The place of geology in university curricula varies widely. In Glasgow, for example, the subject is flourishing, the classes are relatively huge, and the value of the subject is appreciated both by the students and by the people responsible for educational policy. All arts students must study one science subject, and that most widely chosen is geology. The fact that there is no other subject better fitted than geology to give a general insight into scientific methods seems to be realised. It is, unfortunately, far otherwise in London and elsewhere, where geology is moribund and appears to be at the point of extinction. The success of an honours school can only be judged by the number of honours degrees awarded year by year. From this point of view probably the less said the better.

In the recent revision of the regulations governing science courses, it has made almost impossible for an honours school in geology to survive in London. The numbers of would-be entrants into the schools of the university is so large that all the places available are allocated to students who have passed intermediate or an equivalent examination. True, as a concession the geological

staff are being allowed to organise first-year courses, but geology cannot stand alone in this respect. The numbers to be admitted next session are determined almost entirely by the laboratory accommodation in the big subjects. Frankly, the mathematicians, chemists and physicists who so overwhelmingly outnumber and outvote geologists on governing bodies of all sorts have little interest—most of them none at all—in the survival of geology.

In the past honours geologists have been recruited from two sources : first, the very few who were educated at schools with geology on the syllabus ; second, those who, on the advice of the Dean were recommended to take geology as a fourth subject for intermediate—there was usually no difficulty in finding the other three among subjects normally taught in schools. Now this latter source is completely dried up. Students are deprived of that invaluable first year, when they were sampling, as it were, four different subjects, and at the end of which they were free to choose their special subject as a result of their own experience.

The future is not entirely black, however, though it is dark enough to cause much misgiving to those interested in the future of geology. The new scheme for the honours degree in chemistry in London gives students an option of choosing geology as one of three ancillary subjects. Here geology is in competition with biology and physiology ; biology is becoming increasingly popular in schools, so again we are under a disadvantage, and a lot depends upon the nature of the courses offered to the chemists and the trouble the teachers responsible are prepared to take to make the experiment a success. Similarly the Geography Board in the university have made a one-year geology course compulsory for all honours candidates in their subject, and a second-year course optional. From my experience, once we get these students in the first year, there are very few who do not choose to take the more advanced course. Here then is our hope for the future : there promises to be an influx of students taking the subject to ancillary, or subsidiary standard.

Year by year numbers of teachers are being turned out by the universities with a good honours degree in geography, and with a good knowledge of the contribution geology can make to their own subject. It is to be hoped that in due course this body of informed opinion will become sufficiently strong and vocal enough to make itself heard in the councils of those who control educational policy.

Dr. L. J. Chubb : I am happy to say that I do not share Dr. Wells's pessimistic outlook on the future of geology in London University, in fact I think the prospect has never been brighter. It is true that this year half a dozen colleges can between them produce only one candidate for the special degree, but this is an aftermath of war. University College alone has four students expecting to sit the special geology examination in 1947.

At our college the problem is not a shortage of students, but a shortage of accommodation and equipment adequate for the great post-war influx which has already started and is likely to swell considerably in coming sessions. Before the war our average annual intake of new geology students was 12 ; this year it was 26 ; when the new regulations come into force, under which a one-year course of geology will be compulsory for all geography students, the number is likely to rise to 40 or 50. In the past some 66 per cent. of first-year students have been sufficiently attracted to the subject to want to continue it for a second year and eight per cent. have decided to specialise. These proportions still hold good and I anticipate that in the future our second-year class will rise to 25 or 30, and we will send in some four or five candidates for the special degree every year.

Several speakers have commented on the shortage of school-teachers qualified to teach geology. I do not understand this, as for the last quarter of a century every university in the country has been turning out large numbers of geography graduates who have taken geology as their subsidiary subject. Many hundreds of these graduates must now be teaching in the schools and all are well qualified to teach geology to the higher school standard. A certain number of chemists also have taken subsidiary geology.

Any school that lacks the necessary collection of rocks, minerals and fossils should get into touch with the geology department of one of the universities or university colleges. Many of them have sufficient duplicate material to supply a collection of one or two hundred specimens to any school requiring them. I was able to help an East Anglian grammar school in this way two or three years ago.

Teachers need not hesitate to encourage promising boys to consider making geology their profession, especially those who are willing and fit to go abroad. For many years past the supply of trained geologists has fallen considerably short of the demand. For girls the position is less certain as the conditions of service in many geological posts are regarded as unsuitable for women. However, there are certain types of geological work open to them, as Dr. K. P. Oakley has shown in an article in the journal *Women's Employment* for June, 1945.

VI. SHORTER CONTRIBUTIONS

Mr. W. B. West : For the last quarter of a century geography has been changing from the mere memory subject it once was to training in deduction from observed facts.

Thus it has become the study of the exploitation of the surface of a planet by man. The main factor in the development of primitive man was climate, the geological structure of his homeland

reacting only indirectly by way of the vegetation incidental to the soil on which he lived. As he progressed, the geology of his country helped or hindered industrialisation in providing him with raw materials and tools to fashion them, or even only the latter.

Our geography today then is the study of man reacting to the two factors of climate and the geology of his habitat, and geology has every right to inclusion as a school subject.

Mr. H. J. W. Brown : The scientific staff of Purley County Grammar School favours an advanced course in geology and make the following comments : *Biology*, "a knowledge of palaeontology is necessary for the study of evolution." *Physics*, "a knowledge of the physical properties of minerals would be useful, a study of polarised light is included in the VI Form syllabus." *Chemistry*, "a study of minerals would be valuable. A knowledge of the crystal systems and the use of polarised light in organic chemistry is important." There is also a demand for the study of some geology from the geography and history specialists.

Geology can be taken as a subject in the London University Higher School Certificate examination, but not for London University General School Certificate.

The new Burnham salary scales for teachers are not high enough to attract well-qualified science graduates into the schools and industry offers more remunerative employment. Few men would read geology to teach it in grammar schools.

I suggest that a committee of the Geologists' Association consisting of members teaching the subject in schools be formed to discuss syllabuses, arrange for the exchange of teaching material from different parts of the country, and to co-operate in planning field excursions. It might be possible for one school to act as host to another school in a different part of the country. Council for the promotion of field studies and youth hostels might help to solve some of the problems connected with long-distance field excursions.

It seems that for many years an army of occupation must be kept in Germany. This raises a serious problem for the boy in the sixth form who may be able to complete his Higher School Certificate course, but not able to enter the university on account of his service with the Forces for three years. Is there any provision for geology in the Forces' educational courses ? This may not be relevant to the subject under discussion, but one such case has recently come to my notice.

Mr. A. H. Gunner : I feel that geologists as a faculty are much too self-centred and aloof, and when opportunities occur for public presentation the faculty becomes defeatist and apologetic or entirely neglects to state a case at all. A good example of this

was the recent main article on water divining in the *Observer*. It ought to have been answered by some geologist of authority and the author adequately trounced. Heaps of such opportunities arise in all kinds of mediums, but are we too Quakerlike a brethren ever to emerge from our twilit conventicles?

We must declare a gospel or eventually be discounted. No science, not even astronomy, could have such magic material or such a thrilling story to tell. Nor one so intimately bound with Destiny. Are we not all potential fossils?—and every sedimentary rock (and no doubt some others) somewhere tells of our lineage. Make it a human story.

Here are some practical ways of arousing the interest without which no parent is going to recommend his offspring to pursue geology.

1. Continually batter away at the Ministry of Education. They are keen enough on nature interests and every village school has its neighbouring quarry. Advise that such units of interest should be adopted for long-term observation and investigation, and records. Let the kiddies have a table at the local annual flower show to exhibit their fossils, and let there be prizes.
2. Encourage museum councils to insist on some modicum of geology as a qualification in the curator appointments.
3. Note the rare but very valuable contributions to such pedagogic journals as the *Science Master's Journal*. This is a start, anyway. It is very thoroughly read by all science masters in all secondary schools, but of course the chemists and physicists overwhelm its pages. We must be more aggressive everywhere!
4. Stamp's new book, *Britain's Structure and Scenery*, and Swinnerton's *Solving Earth's Mysteries* are excellent examples of bright, colourfully presented, popular books. How dreary against these are the old type with their tortuous technical jargon, and pulselessness!
5. Bodies like the Workers' Educational Association are crying out for local lecturers. I know from personal experience how difficult it is to get them. Could not a geologist occasionally perform? These people get very keen and critical audiences, and pay a reasonable fee. Here is a field for an evangelist or two from our ranks.
6. I think that geology should stand on its own reputation, not act as the amiable eunuch attendant on geography. Do the universities think this sufficiently strongly to recommend geology as a specific School Certificate subject?
7. We must begin with the very young. Boys revel in fossil hunting, are quick-eyed and nimble explorers. They deserve every encouragement. A bright page in their school magazine,

- a factually accurate but gay textbook, an occasional fillip from B.B.C. children's hour or school broadcast. I think prize schemes might well be recommended. Are most academic geologists bachelors or confirmed adults ?
8. Much more journalism. I believe the daily papers, at their wit's end to strike a new chord in the human breast, would welcome, like a dream come true, good controversial copy on quarries, early mammalian fossils, etc. "Oil in Britain" did not get much of a show, yet all the non-geologist people I meet are thrilled by the new war-time borings. The recent very full report in *The Times* of geological work in Africa had good pictures and attracted much attention and interest.

All this boils down to a vigorous *evangel* within and without the educational field. I suppose it is all limited by funds, but if it were possible for this Association to employ—possibly with the connivance or active assistance of the Ministry—a salaried representative to visit schools and market our gospel, I feel it would be good business promotion. Perhaps the universities would care to release a professor amongst us occasionally ?

Geology gives a third dimension to science, especially is this seen in so-called general science. It is *observational* in practice, and *deductive* in technique, squares all the time with reality, is essentially a field study. Therefore, all the way round an ideal training and inspiration. The divinity master says "It makes, man appear a mere incident in Time," and a senior physics master said to me recently, "Other subjects boys can drop when they've passed the exam., but *your* damned science becomes a positive obsession through life!" These are testimonials that should inspire and reassure us.

* * * * *

After each contribution the President made brief comments leading up to the next. He had himself taken geology as a subject for the higher certificate in 1903 ; he was entirely self-taught, got a pass, and learnt that he had been one of four candidates in the United Kingdom : considerable progress had been made since that date.

He welcomed a statement by Miss D. Clarke that she had recently given a scripture lesson on one of the psalms, which ended in geology ; he first met the excellent account of contemporary metal-mining in the XXVIII chapter when the Book of Job was set as a school subject.

In fact, there were few school lessons which did not provide occasional contacts with geology. In the classics the professedly scientific writers, such as Strabo and Theophrastus or the Elder Pliny and Seneca, were not usually read at school ; but there was much geology in Herodotus, whose *Historia* would be better

translated as "Researches" than as "History." Not only were the Greek and Roman views on theoretical geology and their practice in mining, quarrying and water-supply surprisingly good, but they were familiar to all educated men : Plato on soil-erosion and well-sinking, Demosthenes on mining law, Ovid on fossils, the Younger Pliny on the eruption of Vesuvius and many other instances from authors often read in schools might be mentioned.

It was, however, specially important that students of other sciences should learn, not so much geology as a subject in itself, for which they might have neither the time nor the aptitude, but the nature of the information which geologists could supply. He had himself come across instances of chemists holding important posts who were totally ignorant of the fact that a geologist could tell them what chemical compounds were present in a mineral or rock. Three hundred years ago a Dominican Friar, writing on education, remarked that "he who knows one science only does not really know that one any more than the rest."¹ Every geologist realises his dependence on the work of physicists and astronomers, chemists and biologists, and avails himself of their results ; but, to a serious extent, other sciences and professions are ignorant of the scope of geology, fail to recognise the geological factors involved in some of their problems, and do not avail themselves of geological assistance. Elementary instruction at the public or secondary school level should go far to remedy this weakness.

VII. EDITORIAL COMMENTS

It is quite clear that geologists themselves are strongly in favour of including geology as a subject in the school course. The only dissenter (p. 31) is not internally consistent, for he himself taught geology in school, was highly successful in his remarkably individual manner, and only gave it up because of a disagreement with "——— University."

Certainly, also, geology is a popular school subject. All teachers who have tried it are unanimous on this point. Very few pupils, however, have the staying power of a Joysey (p. 32), and no one would expect it of them. If geology is to be taught the way must be made easy.

What of the way ? The concensus of opinion seems to be that geology is best taught as part of an introduction to science for all scholars in the 10-14 age-groups. After this the paths divide, the science students concentrating on the exact sciences up to the General School Certificate examination, and the art students retaining an acquaintance with geology as a cultural background to other courses. Geology may be reintroduced for science students as a subject for the Higher School Certificate. As will have been seen,

¹ Campanella, 1568-1639, quoted in Jowett, *Introduction to Plato*.

however, there are many variations possible, and the whole question is so intimately bound up with the personality of the teacher, the facilities available, and the nature of the surrounding country, that no hard-and-fast rule can be laid down.

One thing, however, is clear. It is the duty of all geologists who have the interest of their science at heart to introduce it to the widest possible audience. This can only be done by the provision of suitable text books, by the delivery of lectures to schools and training colleges, and by the arrangement of field trips for the unversed amateur. In this connection the Editor invites any schoolmaster who has a party of students interested in geology or physiography, and who is uncertain of his own powers to lead a week's field trip, to write to him. It may be possible to arrange a "joint junior field trip" for scholars from several schools during the summer vacation.

THE ANNUAL REPORT OF THE COUNCIL OF THE GEOLOGISTS' ASSOCIATION FOR THE YEAR 1946

[Adopted at the General Meeting on March 7th, 1947, as the
Annual Report of the Association.]

THE numerical strength of the Association on December 31st,
1946 was as follows :—

Honorary Members	22
Ordinary Members :—	
Life Members (compounded)	129
Annual Subscribers	1202
	1353

During the year 163 new members (a record number) were elected, and the Association lost 110 members through death, resignation and removals under Rule XI for failure to pay subscriptions. The membership continues to rise, and shows an increase of 53 over that of the previous year.

The list of deceased members is as follows : H. M. Atkinson, P. Barnett, R. E. Crossland, F. N. Gossling, E. G. Radley, A. W. Rogers, T. B. Russell, C. A. Sansom, W. G. Shannon, H. J. Snell and Sir Harold Stiles.

Obituary notices will be found on pages 67–70.

FINANCE

The Association is at present in a sound financial position, although the heavy increase in almost all items of expenditure gives rise to some anxiety for the future. For the present, however, in the various Special Funds, apart from the Reserve Fund for Index and List of Members, there are balances amounting to £269 7s. 9d. available for the general purposes of the Association, and the Balance Sheet shows, in addition, accumulated funds amounting to £136 2s. 6d. The income from admission fees and annual subscriptions, at £642 10s., establishes a new record, and is £41 10s. above last year's record of £601. On the income side of the General Purposes Account, under the heading Miscellaneous Receipts, is included an item of £12 3s. 4d. received from the sale of surplus books. The expenditure side, in addition to the special donation of £50 towards the expenses of the International Geological Congress to be held in London in 1948, includes under the heading Incidental Expenses an item of £20 for the purchase of a second-hand typewriter for the Secretary's use, and £10 for five Henry

Stopes medals for future use ; the last item will ultimately be recovered from the Henry Stopes Memorial Fund when the medals have been presented.

Illustrations Fund

Contributions to this Fund amounted to £42 9s. 10d., from 86 members, or about 6 per cent of the membership. There has been a considerable falling off in the sums contributed to this Fund in recent years. The highwater mark was reached in 1928, when 141 members, about 13 per cent of the membership at that date, contributed £75 10s. In 1935, the year when the present Treasurer assumed office, 118 members, about 10 per cent of the then membership, contributed £70 12s. 11d. The cost per page of printing and illustrating the *Proceedings* has more than doubled since the beginning of the War, and unless the Fund receives greatly increased support from members, it will be difficult, if not impossible, to maintain the present standard of publication.

Henry Stopes Memorial Fund

After defraying the cost of designing and making the dies, and the bronze medal and case used for the first presentation to Mr. A. S. Kennard, the balance of the Fund was invested in the purchase of £265 19s. 2d. Government of Newfoundland 3 per cent Stock, which will yield an income of approximately £8 per annum. The first dividend from this investment was received in January, 1947, after the 1946 accounts had been closed.

BALANCE SHEET, DECEMBER 31st, 1946.

LIABILITIES

To Annual Subscriptions received in advance :—			
In 1943 and 1944 for 1947	£	s. d.	£ s. d.
In 1945 for 1947	1	10 0	
In 1946 for 1947	3	0 0	
In 1946 for 1947	58	0 0	
In 1944 for 1948/51	2	0 0	
In 1945 for 1948/49	1	10 0	
In 1946 for 1948/49	2	0 0	
		68	0 0
Cash received for Admission Fees and 1947 Subscriptions before election		3	0 0
Sundry Creditors :		15	14 7
Messrs. Benham & Co. Ltd.			
Special Funds :			
Illustrations Fund	8	5 7	
Illustrations Fund (Capital)	20	0 0	
Reserve Fund for Index and List of Members	128	0 0	
Compounding Fund	1,740	16 7	
Bequest Funds	774	12 2	
		2,671	14 4
Accumulated Funds at January 1st, 1946		2,758	8 11
Less Excess of Expenditure over Income for the year	163	14 8	
	27	12 2	
		136	2 6
			<u>£2,894 11 5</u>

ASSETS

By Investments (Special Funds) at cost or value when acquired :—			
Bequest Funds—	£	s. d.	£ s. d.
£143 8 9 3½% War Stock	141	14 0	
£150 New Zealand 3½% Stock, 1960/64	122	5 0	
£285 3% Defence Bonds	285	0 0	
£100 3% Savings Bonds, 1960/70	100	0 0	
		648	19 0
Compounding Fund—			
£1,217 2 6 Nottingham Corporation 3% Irredeemable Stock	1,152	13 2	
£200 3% Savings Bonds, 1955/65	200	0 0	
£170 3½% War Stock	152	14 5	
£100 3% Savings Bonds, 1965/75	100	0 0	
		1,605	7 7
Illustrations Fund (Capital)—			
£21 0 10 Metropolitan Water Board 3% B Stock	20	0 0	
Annual Subscriptions in Arrears, £87, estimated to realise	30	0 0	
Admission Fees in Arrears, £19, estimated to realise	14	0 0	
Cash at Bankers and in hand :			
at Bankers	168	0 4	
In Office	10	16 9	
		178	17 1
Special Funds :			
Illustrations Fund at Bankers	8	5 7	
Compounding Fund at Bankers	135	9 0	
Reserve Fund for Index and List of Members at Bankers	128	0 0	
Bequest Funds at Bankers	125	13 2	
		397	7 9
			<u>£2,894 11 5</u>

SPECIAL ACCOUNTS

ILLUSTRATIONS FUND.

To Balance in hand on January 1st, 1946			
Donations and Subscriptions...	£	s. d.	£ s. d.
Transfer from Illustrations Fund (Capital)	15	3 3	
	42	9 10	
	12	6	
		£58	5 7
			<u>£58 5 7</u>

By Transfer to General Purposes Account for Illustrations...			
Balance December 31st, 1946, at Bankers	£	s. d.	£ s. d.
	50	0 0	
	8	5 7	
		£58	5 7
			<u>£58 5 7</u>

SPECIAL ACCOUNTS (continued).

ILLUSTRATIONS FUND (CAPITAL).

To Balance in hand on January 1st, 1946	£	s.	d.
" " Dividends as received:—	...	0	0
£21 0 10 Metropolitan Water Board 3% B Stock	...	12	6
	<u>£0</u>	<u>12</u>	<u>6</u>

COMPOUNDING FUND

	£	s.	d.	£	s.	d.
To Balance in hand on January 1st, 1946	...	...	128	19	10	0
" " Composition Fees received during the year	...	...	105	0	0	0
" " Dividends as received:—						
£1,217 2 6 Nottingham Corporation 3% Stock...	36	10	2			
£170 0 3½ War Stock...	5	19	0			
£300 0 0 3% Savings Bonds	9	0	0			
			51	9	2	
				<u>£285</u>	<u>9</u>	<u>0</u>

RESERVE FUND FOR INDEX AND LIST OF MEMBERS.

To Balance in hand on January 1st, 1946	...	...	£	s.	d.
" Yearly Reservation for 1946	...	...	...	88	0
	...	...	...	40	0
			£128	0	0
			By Balance December 31st, 1946, at Bankers	...	£
				...	128
				...	0
				...	0

BEQUEST FUNDS:

	£ s. d.	£ s. d.
To Balance in hand on January 1st, 1946	...	153 16 8
Dividends as received:—		
£143 8 9 3½% War Stock	...	5 0 6
£150 0 0 New Zealand 3½% Stock	...	5 5 0
£285 0 0 3% Defence Bonds	...	8 11 0
£100 0 0 3% Savings Bonds, 1960/70	...	3 0 0
		21 16 6
		£175 13 2
By Transfer to General Purposes Account	...	50 0 0
Balance December 31st, 1946, at Bankers	...	125 13 2
		£ 175 13 2

"TRUST" FUNDS.

FOULERTON AWARD FUND.

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1946	...	...	13 11 8	By Award to A. G. Bell, I.S.O., B.Sc., F.G.S.	...	...	...
" Dividends as received : £255 0 0 Southern Railway 5% Guaranteed Preference Stock	...	...	6 13 11	" Balance 31st December, 1946, at Bankers	...	...	10 0 0
" Income Tax repayment for 1945-46	...	...	6 7 6				16 13 1
			<u>£26 13 1</u>				<u>£26 13 1</u>

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND.

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1946	...	...	60 0 0	By Balance 31st December, 1946, at Bankers...	...	...	...
			<u>£60 0 0</u>				<u>£60 0 0</u>

HENRY STOPES MEMORIAL FUND.

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1946	...	...	375 0 0	By Designing and making dies	...	...	...
			<u>£375 0 0</u>	" Making bronze medal and case	...	...	...
				" Purchase of £265 19 2 Government of Newfoundland 3% Stock, 1943/63	...	...	...
					...	...	...
					...	...	273 0 0
							<u>£375 0 0</u>

We have compared these statements with the books and accounts presented to us and find them to agree.

We have also verified the investments of £1,217 2 6 Nottingham Corporation Stock, £200 3% Savings Bonds, 1955/65 £100 3% Savings Bonds, 1965/75, and £170 3½% War Stock of the Compounding Fund, £255 Southern Railway 5% Guaranteed Preference Stock of the Foulerton Award Fund, £143 8 9 3½% War Stock, £150 New Zealand 3½% Stock 1960/64, £285 3% Defence Bonds and £100 3% Savings Bonds 1960/70, of the Bequest Funds ; £21 0 10 Metropolitan Water Board 3% B Stock of the Illustrations Fund (Capital), and £265 19 2 Government of Newfoundland 3% Stock, 1943/63, of the Henry Stopes Memorial Fund.

E. C. MARTIN, *Treasurer.*
1st February, 1947.

G. A. KELLAWAY } *Auditors.*
J. D. WEAVER }

PUBLICATIONS

Publications Committee.—This committee consisted of the officers (seven) together with Mr. E. E. S. Brown, Mr. T. Eastwood, Dr. R. W. Pocock, Prof. H. H. Read, Dr. R. M. Shackleton, and Mr. G. S. Sweeting. The Committee met on five occasions and considered 21 original papers and two Field Meeting reports. Recommendations regarding these were made to the Council.

The Proceedings.—The increasing size of the volume for 1946 is a welcome sign of return to normal conditions. Containing 334 pages, 25 plates and 57 text-figures, volume LVII is the largest to be published since 1941.

The paper on "The Relationship of Slaty Cleavage and Kindred Structures to Tectonics" is something of an innovation for the *Proceedings*, since it attempts to review the whole state of knowledge in its one restricted field in a manner understandable to the non-expert. Similar papers will be sympathetically received.

MEETINGS

Ten meetings were held, at which four papers were read, one paper was read in abstract, and two lectures were given. One meeting was devoted to a Discussion on "Geology in Schools." Particulars of these will be furnished later in the Session Report.

The thanks of the Association are due to the Authors and Lecturers. The attendance at meetings was well above last year, averaging 96.

The Ordinary and Annual General Meetings were held at the apartments of the Geological Society of London and the Committee meetings at the Imperial College of Science and Technology (Royal School of Mines).

The Association's thanks are due to the respective authorities for the generous facilities afforded.

REUNION

The Annual Reunion was held at the City Literary Institute on Saturday, 2nd November. A number of interesting exhibits were shown, and the attendance exceeded that of last year. Thanks are due to the authorities of the City Literary Institute, the organisers and the members concerned.

A full account of this meeting will be given in the *Proceedings*.

FIELD MEETINGS

The Committee consisted of the officers (seven), together with Miss J. Biggar, Messrs. E. E. S. Brown, G. A. Kellaway, J. F. Kirkaldy, G. S. Sweeting, J. D. Weaver and Vernon Wilson.

Sixteen meetings were held as follows : half day, five ; whole day, seven ; week-end, three ; full week, one. The average attendance was 29. A number of reports have appeared in the *Proceedings*, and it is hoped to publish others later.

The best thanks of the Association are due to Directors and others who organised and assisted in the meetings.

THE LIBRARY

Shortly before his death the late Dr. A. W. Rogers, of Capetown, South Africa, presented to the Association the greater part of his valuable library of geological books. Consisting of over 180 standard works, some rare and valuable, and a number of maps, this is probably the most munificent gift ever received for the Library. Thanks are also due to the donors of a considerable number of other books, pamphlets and maps ; a list will be found elsewhere in the *Proceedings*. The Rev. W. M. Teape bequeathed a small series of books and geological maps to the Association.

Exchange arrangements have now been resumed with a number of foreign institutions with whom communication was interrupted during the War, and in many cases the publications issued by them during the period in question have now been received. The British Council is thanked for much help in this connection.

A loan series of geological maps, mounted and folded for the use of members in the field, has been instituted. The maps presented by Dr. Rogers form the nucleus of this collection, and thanks are due to several other members for adding to the series. Nearly 70 sheets are at present available. The sale to members of a number of duplicate works belonging to the Library realised the sum of about £13, part of which has been devoted to the mounting of maps for the loan series.

NORTH-EAST LANCASHIRE GROUP

Chairman : J. Ranson, A.M.I.M.E., F.G.S.

Secretary : A. Bray, M.Sc., A.Inst.M.M.

During the year five lectures were delivered and three Field Meetings were held.

At the Annual General Meeting the Chairman and Secretary were re-elected with a new Committee. The thanks of the Group to the Education Committee and the College authorities for the use of rooms in the Blackburn Technical College was proposed and carried.

MIDLAND GROUP

Chairman : D. Parkinson, D.Sc., Ph.D., F.Inst.P., F.G.S.

Secretary : Miss Grace M. Bauer.

Committee : Professor L. J. Wills, J. A. Best, A. L. Lyon, J. C. Parrack and E. J. Pegg.

During the year, four Lecture Meetings were held at the Geological Department, the University, Birmingham, and there were Field Meetings. Particulars will be published in the *Proceedings*. The attendance was well maintained.

Thanks are due to Professor Wills for the use of the Geology Department at the University, Birmingham.

WEALD RESEARCH COMMITTEE

Members of this Committee have conducted several Field Meetings during the year. Dr. A. J. Bull held a half-day meeting in the Godstone district on May 1st. At Whitsun a Field Meeting of four days was held in the Weald with Horsham as centre. The directors were Prof. S. W. Wooldridge, Dr. P. Allen, Dr. A. J. Bull, Dr. J. F. Kirkaldy, and the Rev. J. W. Reeves. On September 28th Dr. Kirkaldy directed a whole day meeting at Reigate, Surrey.

Several pieces of work are in progress including the completion of unfinished observations by the late Frank Gossling, and it is hoped to issue reports in the near future.

TRUSTEES

The Trustees of the Association are :—

Managing : Mr. F. N. Ashcroft, M.A., F.G.S., F.C.S., F.R.G.S., Mr. S. Hazzeldine Warren, F.G.S., and Dr. W. F. Fleet, M.Sc., A.R.I.C., A.C.P., F.G.S.

Custodian : The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD

The Foulerton Award for the year was given to Mr. A. G. Bell, I.S.O., B.Sc., F.G.S., for services rendered to geology.

HENRY STOPES MEMORIAL MEDAL

The first Henry Stopes Memorial Medal was presented to Mr. A. S. Kennard, A.L.S., F.G.S.

HOUSE LIST

Professor H. H. Read retires as Vice-President and Messrs. Bottley, F. Jones and Miss E. White as Ordinary Members of Council. Thanks are due to these members for services rendered to the Association.

REPORT OF THE SESSION, 1946

Ordinary Meeting, 4th January, 1946.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

James Henry Aitken, Leslie Stephen Richard Bartlett, Patricia Mary Bluek, William Edwin Brown, Guyon B. G. Bull, B.A. (Cantab.), Herbert William Burgess, John Norman Carreck, Betty Clark, Michael Luther Kingdon Curtis, Jean M. Dyer, Joseph Edward Gladwin, Gillian Elisabeth Groom, Mrs. Kate Hammond, Frank Geoffrey Keightley, Herbert Richard Lovely, Alexander McGill, Elizabeth Napier, Charles Bernard Payne, and Charles William Pegg were elected Members of the Association.

Messrs. G. A. Kellaway and F. W. H. Migeod were elected to audit the accounts for 1945.

The following lecture was delivered :—"A Geologist's Visit to Soviet Russia," by Wilfred N. Edwards, B.A., F.G.S.

Ordinary Meeting, 1st February, 1946.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Valerie Jesseman, Jean Marshall, Edgar Merrington Martin, Brian H. Mottram, Ernest Mark Porter, Walford Teale, M.A., and Edmund Wright were elected Members of the Association.

The following lecture was delivered :—"Impressions of the Tectonics of Kenya," by R. M. Shackleton, B.Sc., Ph.D., F.G.S.

Annual General Meeting, 1st March, 1946.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

The Annual Report of the Council (already circulated) was taken as read. It was moved by Dr. Hollingworth and seconded by Mr. G. Bond "That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1945." The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of the Council in accordance with Rule XIII :—President, C. E. N. Bromehead, B.A., F.G.S.; Vice-Presidents, Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., R. W. Pocock, D.Sc., F.G.S., T. Eastwood, A.R.C.S., F.G.S., A. S. Kennard, A.L.S., F.G.S., G. S. Sweeting, D.I.C., F.G.S.; Treasurer, E. C. Martin, B.Sc., A.R.I.C., F.G.S.; Secretaries, General—R. Reeley, F.G.S., Field Meetings—G. W. Himus, Ph.D., M.I.Chem.E., F.G.S., Publications Committee—A. J. Bull, Ph.D.,

M.Sc., F.G.S. ; Editor, Alan Wood, B.Sc., Ph.D., F.G.S. ; Librarian, L. R. Cox, M.A., Sc.D., F.G.S. ; twelve other Members of the Council, E. P. Bottley, F.G.S., S. Buchan, B.Sc., Ph.D., F.G.S., L. J. Chubb, Ph.D., M.Sc., F.G.S., W. Dack, I.S.O., F.G.S., C. T. A. Gaster, F.G.S., F. Jones, T.D., Ph.D., M.Sc., F.G.S., A. T. Marston, L.D.S., F.G.S., F. W. H. Migeod, F.R.G.S., F.R.A.I., Miss Mabel Tomlinson, B.A., D.Sc., Ph.D., F.G.S., Miss E. White, B.Sc., F.R.G.S., D. Williams, M.Sc., Ph.D., B.E., F.G.S., Vernon Wilson, B.Sc., Ph.D., D.I.C., F.G.S.

It was moved by Mr. R. Melville, seconded by Mr. J. A. Richardson, and duly carried, "That the best thanks of the Association be given to the retiring President, the Officers, the retiring members of Council, and the Auditors."

The Foulerton Award was presented to Mr. A. G. Bell, I.S.O., B.Sc., F.G.S., in recognition of services rendered to the Association.

The President said :—

Mr. Bell. The Council has unanimously awarded you the Foulerton Award for the great services you have rendered to the Association. Elected to the office of General Secretary in 1937, your modesty soon endeared you to us all, and you carried the heavy burden entailed by that office during the most critical period in the history of our country. In 1939 the Great War began, but there was no question of evacuation on your part, though your age more than entitled you to it, you stuck to your post and the Association went on with its good work though not exactly as in times of peace. Your residence was in an area termed officially "neutral" but it soon became dangerous. Officials never make mistakes and the area remained "neutral" to the end. After several "near misses" at last in 1944 you were forced to go to, but not "sent to" Coventry, and with deep regret we had to accept your forced resignation. But your work had successfully carried us over the worst period, and this work will be long remembered by us all. It affords me the greatest pleasure to hand you this slight recognition of what you have done for us.

Mr. E. Ernest S. Brown, M.B.E., F.G.S., Dr. A. J. Bull, M.Sc., F.G.S., Dr. Marie C. Stopes, F.G.S., F.L.S., and Mr. G. S. Sweeting, D.I.C., F.G.S., were elected Honorary Members of the Association.

The President then delivered his address entitled "Fifty and one years of the Geologists' Association."

It was moved by Mr. A. G. Davis, seconded by Miss Muir Wood, and duly carried, "That the President's Address be printed and circulated among the members."

The Chair was then vacated by the retiring President and taken by the new President, Mr. C. E. N. Bromehead, B.A., F.G.S.

The founding of the Henry Stopes Memorial Medal was announced and Dr. Marie C. Stopes, F.G.S., F.L.S., was invited to make the first presentation to Mr. A. S. Kennard, A.L.S., F.G.S.

The President said :—

Ladies and Gentlemen, members of the Geologists' Association. I must first thank you for the honour you have done me in choosing me as your president. I can assure you that I will do my best to serve the Association, though my best efforts can be only a meagre return for all the benefits I have received through more than 40 years of membership.

Moreover, I am called upon to occupy this chair for the first time—in my own right—on an occasion unique in the history of the Geologists' Association—unique in several respects in that of scientific societies in this country. You have several times suffered from my taste for things ancient in the human as well as the geological time-scale, so now I would remind you of the counsel, given about the year 180 B.C. by a very wise man, who is more usually referred to as the son of his father than by his own name.

"Let us now praise famous men and our fathers that begat us . . . their name liveth for evermore . . . and some there be which have no memorial." I fear that Henry Stopes was nearly approaching the latter class. I had known of him as a Pioneer in Pre-history and in Pleistocene geology since I began Survey work in the Thames Valley in 1910, when another pioneer, William Whitaker, advised me to study two publications: the list of fossils from Swanscombe by Henry Stopes, and the paper on the gravel terraces by Hinton and Kennard. No doubt my contemporaries and seniors remember his work, but I wonder how many of our younger members had heard of him before receiving the circular for this meeting.

As long ago as 1881, Henry Stopes read a paper to the British Association on a shell carved by prehistoric man; that paper was discussed by an earlier and better-known authority, Joseph Prestwich. At the same meeting, Stopes also read one which has a special appeal to me, on the ores and minerals of Laurium, as worked by the Athenians in 500 B.C.

Today he is to be placed amongst those whose "name liveth for evermore." From today our Association has a medal to bestow triennially in memory of Henry Stopes, Pioneer, for work on Prehistoric Man and his Geological Environment. The full conditions of the award will be laid before you in due course, and I need now emphasise only two points: preference is to be given to non-professional work; I regard our Association as intended mainly for amateurs; but in the true sense of that word nearly all professional geologists are amateurs of geology and much of the work that they expound to us in the field or the lecture-room is done in their own time, and is non-professional. Secondly, all members of the Association, not merely members of Council, are to have a part in the choice of the medallist.

On this first occasion the choice has appropriately been entrusted to Henry Stopes's daughter—appropriately in that she does honour, in the words I quoted, to the father that begat her and that, like him, she is a pioneer. Dr. Marie Stopes has been one of our members since 1911. She is known throughout the geological world as a pioneer in the geology of Japan, in palaeobotany generally, and in the constitution of coal. You have just shown your appreciation of her eminence as a geologist by making her an honorary member. Some of you may be aware that she is also a poet.

In a recent poem, she has spoken of Truth as the many-veiled goddess. Her father lifted some of the outer veils from the truth about prehistoric man; but as an earlier poet has said, "veil after veil will lift, but there must be veil upon veil behind." There will always be work to be done to earn the Stopes Medal!

Now a pioneer daughter is here to do honour to a pioneer father; the Council has asked Dr. Stopes to present the first medal, and she has consented. It is, therefore, not my province to say anything as to the reasons for her choice of a recipient, but I must quote you some words of Henry Stopes himself: in the year 1890, in the preface to one of his prehistoric papers, he says: "The unknown is still infinitely greater than the known, rich as it is to us. It is given to every faithful worker to add to the present fund of common knowledge, in which each additional fact helps to bring out others." Much has been added since that date, and I feel sure we shall all agree that no one living has been a more faithful worker, nor has added more to the fund of knowledge concerning Prehistoric Man and his Geological Environment than he who vacated this chair only a few minutes ago. It is my privilege to call upon Dr. Marie Stopes to present the first Henry Stopes Medal to Mr. Kennard.

On the presentation of the first Henry Stopes Memorial Medal, Dr. Marie Stopes said :—

Mr. Alfred Santer Kennard. The amateur, as distinct from the professional, has always been dear to the heart of Britain, and no science owes more to distinguished amateurs than does geology. Many of its greatest pioneers have been amateurs, noblemen, gentlemen of leisure, businessmen, manual labourers, filled with the true spirit of science, the burning desire to find out *why*, and, without guile or subsidy, to work on the discovery of truth.

My father, Henry Stopes, whose Memorial Medal is now being inaugurated, was such a man, a busy professional architect who devoted a great deal of his time to geology and prehistory. How varied were his achievements in these sciences is illustrated by the titles of the papers he read, when, as a young man, he first appeared on the platform of the British Association. In 1880 and 1881 he read six diverse papers. In 1880, "On a Palaeolithic Stone Implement from Egypt" (this was the very first palaeolith found in Egypt and cost him the friendship of Sir John Evans), "On a Palaeolithic Implement from Palestine" and "On the Salting Mounds of Essex." In 1881, "On Some Ores and Minerals from Laurium, Greece," "Traces of Man in the Crag" and "Some Results of the Removal of the Malt Tax."

You, Alfred Santer Kennard, have worthily followed the non-professional tradition in geological science, devoting all your spare time to its study. You have been attracted by the Tertiary Deposits, especially the Post-Pliocene. Like the true amateur detective, you collected clues somewhat disregarded by others, and from the non-marine Mollusca of every available section you accumulated results of great value to all workers in the geological periods you covered. Published by this Association, your last paper on the Crayford Brickearths, and your Presidential Address on Kent's Hole, are recognised as standard works.

Although you sought the mollusca with a penetrating eye, you did not confine your attention to them, but whenever possible you also collected fragments of the smaller vertebrata and the associated human artifacts as material for the work of other specialists.

You have for long given attention to flint implements, and the much-debated Eoliths, championed by my father some years earlier, were critically examined by you in 1898 and their human origin defended.

In 1905, with M. A. C. Hinton, you maintained that in this country there was a stratigraphical succession from the most primitive of tools to the highly finished neoliths. It is not too much to say that this paper, published by this Association, was the foundation of later work by others on the subject.

Those digging for archaeological evidence soon sought your help, and many of their reports contain Appendices, the result of your illuminating study of their material.

When my father made his important discovery of extinct mollusca cheek-by-jowl with human tools, in bedded deposits in the Thames Valley, it was to you he turned for their identification. You are one of the very few survivors of my father's many friends, and I think certainly the only one who co-operated with him in his later work.

The Geological Society honoured you last year with the award of the Prestwich Medal, and today it gives me one of the greatest pleasures of my life to present you with the first of the Henry Stopes Memorial Medals.

Mr. Kennard replied :—

Dr. Marie Stopes. I must indeed thank you for your kind remarks and for the great honour you have conferred on me by considering my researches in prehistory as being of such value as to deserve the award of the first Stopes Memorial Medal.

Work it certainly was—not in the usual sense of being irksome and as a means of obtaining bread and butter. It was a real pleasure when I could

study the eternal verities in quest of the answer to the problem "What does it all mean?" and this pleasure, as we all know, is ample reward for all the labour. The accumulation of new facts may be slow, but what a delight they are when they are discovered. One such discovery is still vivid in my memory. It was when nearly 50 years ago your father showed me the first shells ever found in the High Terrace at Swanscomb, some still retaining their coloration. Hitherto, practically no contemporary fossils, save implements, had been found, and it had been deduced from this that their absence was due to cold conditions. There on the table was the beginning of a new chapter in Pleistocene geology, and even now it has not been finished.

I know only too well that I have made mistakes, but they were all honest and due to lack of evidence. One lives and learns, especially in geology. Of your father, who was truly a pioneer, I have very kindly memories. He was one of my earliest friends in the true sense of the word, and I owe much to his encouragement and help, and it was with a deep sense of personal loss that this friendship ceased so soon through his early death, mingled with the thought of the heavy blow that it was to prehistoric studies. Elderly as I am, this medal will act as a great incentive to me to continue the researches of a lifetime with the motto which was certainly your father's and is, I trust, mine: "Fiat lux."

Dr. Marie Stopes, I thank you.

Ordinary Meeting, 1st March, 1946.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

John Loughborough Bee, David Eric Brown, John Bernard Calkin, M.A., Roy Reginald Boardman Cox, Charles Edmonds, J.P., F.G.S., Wyndham Bowen Evans, Adrian John Roberts, John Walter Ryde, F.Inst.P., Harold Sowerby, and Frank Martin Taylor were elected Members of the Association.

Ordinary Meeting, 5th April, 1946.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

Rosemary Norah Allen, John MacRae Christian Wellstood Baker, William George Victor Balchin, Thomas Charles Bishop, Leslie Bor, David Lawrence Dineley, Major Percy William Elliott, Hermon French, Cecil Pooley Garner-Richards, James Robert Temple Hazell, Derek W. Humphries, Donald Raymond Hunter, Trevor Collier James, Thomas U. John, Gordon Harris Jones, John Humphrey Jones, Harry Lowery, M.Ed., Ph.D., D.Sc., F.Inst.P., F.G.S., Mrs. Everilda Mary Lowery, Saad Eldin Sobhy El Nakkady, Graham Gordon Pickton, Harry Piper, Adrian Henry Wardle Robinson, James F. A. Stark, Alec Francis Trendall, and Rowena Wilkins were elected Members of the Association.

A Discussion on "Geology in Schools" took place. It was opened by Dr. Vernon Wilson, Dr. R. O. Jones, Miss Mabel Tomlinson and Miss M. M. Sweeting.

Ordinary Meeting, 3rd May, 1946.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

Enrico Cohen, Mrs. Justith Augusta Maria Cohen, Evelyn E. Ford, Miss Ursula Mary Grigg, Frank T. Horrocks, William

Turland Hill, Leonard Hurst, Sidney Leader, Woodford Stanley Gowan Plucknett Norris, B.Sc., Ph.D., A.R.C.S., D.I.C., A.R.I.C., Frank Kenneth North, Joseph David Pearson, Harry Pressley, Doreen E. Stevenson, Norman Thomson, and George Frederick Urry were elected Members of the Association.

The following paper was read :—"Evidence of Submarine Erosion in the Lincolnshire Limestone of Northamptonshire," by J. H. Taylor, M.A., Ph.D., F.G.S.

Ordinary Meeting, 7th June, 1946.—Mr. T. Eastwood, A.R.C.S., F.G.S., Vice-President, in the chair.

James Anthony Charles, William Holt, Ian Douglas Muir, John William Parry, Miss Diana Warren Piper, James Andrew Robbie, Alexander Ian Robertson, Miss Elizabeth Anne Saul, and Henry Thomas, M.A., Ph.D., F.R.G.S., were elected Members of the Association.

The following paper was read :—"The Relationship of Slaty Cleavage and Kindred Structures to Tectonics," by Gilbert Wilson, Ph.D., M.Sc., F.G.S.

The following paper was read in abstract :—"Notes on Wealden Fossil Soil-Beds," by P. Allen, B.Sc., Ph.D., F.G.S. (Weald Research Committee Report).

Ordinary Meeting, 5th July, 1946.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

Ronald Spilsbury Barron, William Alfred Benians, F.A.I., M.R.San.I., Arthur Thomas Boyson, Miss Eila Muriel Joice Campbell, Thomas James Latus, B.Sc., F.R.A.S., F.G.S., John Edmund Laycock Clements, Alfred J. Emerson, Colin Arnold Fothergill, Sydney Archer Gill, Michael Holden, Selwyn Peter Hope, Adrian Paul Humphreys, Jack Ineson, Peter Ernest Pinfold, Lawrence Michael Rice, B.A., Richard Godfrey Morris Spiers, Donald Alexander Spratt, Alan Edward Spratling, Miss Brenda Muriel Stead, F.R.G.S., Daniel Islwyn Thomas, B.A., Miss Margaret Elizabeth de Watteville, and Miss Kathleen Mary Westbrook, were elected Members of the Association.

The following paper was read :—"Piltdown Man : with Special Reference to the Ape Mandible and Canine Tooth," by Alvan T. Marston, L.D.S. Edin., F.G.S., F.R.A.I.

Ordinary Meeting, 2nd November, 1946.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

Peter Herbert Baadsgaard, Miss Catherine Elizabeth Cannon, Ian Wolfran Cornwall, B.A. (Cantab.), William Warwick James, O.B.E., F.R.C.S., L.R.C.P., L.D.S. Eng., John Myers, Edward Pyddoke, Ian Arthur Pegrume Rumsey, D.S.C., and Thomas Whitworth were elected Members of the Association.

The Re-union was then held in the City Literary Institute.
For list of exhibits, see below.

Ordinary Meeting, 6th December, 1946.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

John Barry Allen, Harold William Ball, James Richard Barratt, Margaret Alicia Barrett, Howard Scott Bennett, Rex Leslie Birch, Frederick Ernest Bowen, Arthur William Breed, Cecilia Mary Burbidge, Joseph Gerald Capewell, B.Sc., F.G.S., Vernon Chen, Joseph Coates, A.R.S.M., F.G.S., Ronald A. Colville, Cyril Arthur Cosway, M.Sc., Hilda Mary Margaret Cox, Margaret Dorothy Dixon, Ursula Mary Donnelly, Ralph Eustace Edwards, Bertram Hughes Farmer, Sir Lewis Leigh Fermor, O.B.E., D.Sc., F.R.S., Archibald Forrest, Walter Freeman, A.M.I.Struct.E., André George Gregory, Mary Reid Illing, Donald Edward Jones, Marion Louise Jones, Douglas Kinch, B.Sc., Eric John Lake, Sylvia Anne Lindop, Valerie A. E. Lindsey, Audrey Winifred Mary Lock, Alfred William Thomas Marsh, Francis John Marshall, Marjorie Vivien Mills, Doris Juliet Milner, George Francis Mitchell, M.A., M.R.I.A., Thomas Trevelyan Morris, B.A., Lt.-Col. Charles Shirley Wilmshurst Sabine, Douglas James Shearman, Andrew Slater, George Joseph Snowball, Anthony Kennett del Strother, Bryan Summers, Victor Saville Talbot, Kenneth Taylor, Gordon Thomas Warwick, Maurice Kingsley Wells, B.Sc., and Arthur John White-man were elected Members of the Association.

The following paper was read :—"The Geomorphology of a Part of the Middle Thames Area," by F. Kenneth Hare (Assistant Professor of Geography, McGill University).

LIST OF EXHIBITS

The Association's Albums of Photographs.

Exhibited by Miss Mary S. Johnston.

British Museum (Natural History) Department of Mineralogy.

- (1) Riebeckite in crystalline quartz from Sultan Hamud, Kenya Colony. Collected by Major H. J. H. Lambert, R.E.
- (2) Recent calcareous concretions from the Bourne Brook, Cambridge. Collected by Dr. Pantin and Professor Fritsch and recently described in an article in *Nature*.
- (3) Silica-glass from the crater near Trinity, New Mexico, caused by the explosion of the test atomic bomb.

British Museum (Natural History), Department of Geology.

Marvin and Wallis Collection of polished pebbles from the Isle of Wight.

Geological Survey and Museum.

Reprinted geological maps now available.

Geological Survey and Museum, Palaeontological Dept.

Selection of British Fossils.

Barnard, T., and Weatherhead, A. V.

Some Lias Foraminifera with Photomicrographs.

Bottley, E. P.

(1) A new collection of rocks to illustrate the latest British Standards Specification of road making materials.

(2) Fine minerals and mineral crystals.

Brown, E. E. S.

Brazilian Quartz Crystals and their Inclusions.

Casey, R.

A Brachiopod of unusual interest.

Davis, A. G.

English Nummulites.

Dollar, A. T. J.

Balance weights and gauges made of Rock Crystal.

Dunham, K. C.

Exhibit to illustrate geology of German Barytes and Fluorspar deposits.

Hallimond, A. F.

New petrological microscope.

Himus, G. W., and Himus, Mrs. H.

Mollusca from the shell cliff at John o' Groats. Identified by C. P. Chatwin.

Mourant, A. E.

Specimens from German excavations in the Jersey Shale Series.

Ovey, C. D.

Foraminifera as rock builders.

Trueman, A. E., and MacKay, C.

Air photographs of Pacific Islands and of New Guinea.

Turner, J. G., and Venables, E. M.

Fossils from the London Clay of Bognor Regis and the Bracklesham Beds of Bracklesham Bay.

Wright, C. W., and Wright, E. V.

- (1) The Evolution of the Echinoid genus *Hagenowia*.
- (2) New and little known elements of the fauna of the Claxby Ironstone (Neocomian).

Wrigley, A.

Eocene and Oligocene Cerithiidae and *Cyrena* illustrating a recurring faunal association.

FIELD MEETINGS, 1946

Although conditions still remained difficult, four "long" (including three week-end and one seven-day) meetings were held. The transport position was a little easier, consequently Directors were able to take parties farther afield and were less tied to areas within easy walking distance of railway stations.

The following meetings took place :—

Saturday, 9th March.—A visit to the Imperial Institute, under the direction of Mr. F. W. Rolfe, assisted by Dr. A. W. Groves, and Messrs. E. H. Beard, T. Deans and G. E. Howling. Forty attended.

Thursday, 18th, to Tuesday, 23rd April (Easter).—Ashover, near Matlock, directed by Mr. G. S. Sweeting. Four full days were spent in the field; the party numbered 32. On the last day five members of the North-East Lancashire Group joined in. The party was accommodated in two's and three's in cottages and farmhouses, an arrangement which proved very satisfactory.

Saturday, 4th May.—Professor H. L. Hawkins led a party of between 55 and 60 members and friends on a trip round Reading, during which he demonstrated the varying characters of the Reading Beds.

Saturday, 11th May.—Dr. A. J. Bull led a party of 30 in a traverse from Caterham to Godstone, in the course of which he demonstrated features of interest in the geology and geomorphology of the area.

Saturday, 1st June.—Mr. F. H. Edmunds conducted a party of 29 in a traverse from Boxhill to Dorking. Tea was kindly provided by Dr. M. C. Stopes at her house, Norbury Park, Mickleham.

Whitsun.—Two week-end meetings were held simultaneously, and in spite of very adverse weather conditions, the programmes were successfully carried out.

(a) The Kettering district was visited by a party of 30, under the joint direction of Drs. S. E. Hollingworth and J. H. Taylor,

from Friday, 7th, to Monday, 10th June. The object was to study the succession and superficial structure in the Northampton Ironstone Field.

(b) The work of the Weald Research Committee, both recently completed and in progress, was demonstrated from Saturday, 8th, to Tuesday, 11th June, by Professor S. W. Wooldridge, Drs. P. Allen, A. J. Bull and the Rev. J. W. Reeves.

Saturday, 15th June.—Sir Edward Harrison directed a party numbering 55 in a visit to a number of the classic geological and archaeological sites in the country round Ightham. In addition, a demonstration was given of Eoliths and other implements.

Saturday, 29th June.—Dr. Gilbert Wilson conducted a party of nine in a traverse from Dorking, via Headley Heath to Leatherhead, a route which linked with, and extended the traverse made on 1st June.

Monday, 1st, to Monday, 8th July.—Making their headquarters at Llanberis, a party of 25, directed by Professor W. G. Fearnside, spent a week in studying the geology of Snowdonia.

Saturday, 6th July.—A party of 13, under the direction of Mr. J. B. G. Ainsley, examined a number of exposures which had not recently been visited by the Association, between Newlands Corner and Abinger Hammer.

Saturday, 20th July.—Mr. D. L. Searle demonstrated a number of fine sections in the Pleistocene deposits of the Medway at Upnor, Kent, to a party of 17.

Sunday, 11th August.—Directed by Mr. C. W. Wright, 21 members visited the neighbourhood of Leighton Buzzard.

Saturday, 24th August.—Mr. T. A. Marston demonstrated the sections in the Barnfield Pit, Swanscombe, and the site of the Swanscombe skull to a party of 30. A large number of flint implements, brought by the Director, were also shown.

Saturday, 7th September.—In pelting rain, Mr. C. C. Fagg led seven members in a traverse from Oxted, via Titsey to Limpsfield.

Saturday, 28th September.—Dr. J. F. Kirkaldy conducted a party of 40 round Reigate in an examination of the detailed succession of the Lower Greensand. The lateral extent and variation of the subdivisions along the outcrop between Dorking and Westerham were described, on a basis of the work published by the late Mr. Frank Gossling, supplemented by much hitherto unpublished material bequeathed to the Weald Research Committee.

NORTH-EAST LANCASHIRE GROUP

The following Meetings and Field Meetings were held during 1946 :—

1st March.—Lecture, “Early Man in Southern England,” by Mr. J. Hawkes, F.S.A.

5th April.—Presidential Address, “Some Contacts of Botany and Geology,” by Mr. J. Ranson, A.M.I.M.E., F.G.S.

13th April.—Field Meeting : Upper Rebblesdale. Leader, Mr. J. Ranson, A.M.I.M.E., F.G.S.

4th May.—Field Meeting : Salewheel. Leader, Mr. F. C. Bond.

24th June.—Field Meeting : Heapey and White Coppice. Leader, Mr. G. Urry.

18th October.—Annual General Meeting. Lecture, “Fossil Fungi,” by Mr. T. Lacey, B.Sc., F.L.S.

15th November.—Lecture, “The Ribble Estuary,” by Mr. F. C. Bond.

5th December.—Lecture, “Pleistocene Geology,” by Mr. W. Millward, B.A.

MIDLAND GROUP

The following Meetings and Field Meetings were held during 1946 :—

26th January.—Lecture, “Tectonic Origins,” by Dr. A. J. Bull.

9th February.—Lecture, “Snowdonia as a National Park Area,” by Professor Fearnside.

2nd March.—Field Meeting : Ellows Park and Turner’s Hill. Leader, Professor L. J. Wills.

18th May.—Field Meeting : Drakelow Aircraft Factory, Nr. Kidderminster. Leaders, L. F. S. Wolters and Major Thomas.

5th October.—Field Meeting : Dovedale. Leader, Dr. Parkinson.

26th October.—Lecture, “Geology of the Gold Coast,” by A. Ludford, M.Sc.

14th December.—Lecture, “Geological Structure of North-Western Szechuan,” by Dr. H. B. Whittington.

DONATIONS TO THE LIBRARY DURING 1946

(Except where otherwise stated, the donors are the authors of the works presented)

ARKELL, W. J.—“Standard of the European Jurassic” (1946) and 32 other pamphlets.

- BENNETT, W. H.—“Glacial Chronology and the Pekin and other Prehistoric Skulls” (1946).
- BIGOT, A.—“La destruction des collections et des bibliothèques scientifiques de Caen” (1945).
- BIRMINGHAM UNIVERSITY, DEPT. OF GEOLOGY.—“Petrology of Natural Coke” and one other pamphlet, by C. E. Marshall (1946).
- BOURDIER, F.—“Les glaciations et la chronologie préhistorique” (1943).
- BRAZIL, DEPT. NAC. DA PRODUÇÃO MINERAL.—*Avulso* Nos. 49-51, 53-56 (1942-4) and *Boletim* Nos. 55-57 (1943).
- CARLEY, G. C.—“Geological Excursions round London,” by G. M. Davies (1914); “Encyclopédie par l’Image. La Préhistoire” (no author or date); and other works.
- CASIMIR, M.—“Studies in Folding of the Jersey Shale” (1934) and eight other pamphlets.
- CEYLON, DEPT. OF MINERALOGY.—*Bulletin* No. 2 (1946).
- CHANNON, P. J.—“Notes on some Temporary Excavations across the Cotswolds” and “Recent Exposures of the Lower Lias between Gloucester and Cheltenham” (1946).
- FAIRBRIDGE, R. W.—“Submarine Slumping and Location of Oil Bodies” and “Our Coral War” (1946).
- GASTER, C. T. A.—Nine pamphlets relating to the Chalk of Sussex.
- GEOLOGICAL SURVEY OF GREAT BRITAIN.—*Special Reports on Mineral Resources*, vol. 34, “Rock Wool” (1945).
- GREEN, J. F. N.—“The History of the Bourne and its Valley” (1946).
- HEWITT, H. D.—“Geological Observations on the Eastern Vallies of Norfolk,” by J. W. Robberds (1826); “Recherches sur le terrain crétacé supérieur,” by C. Barrois (1876); “Geology, etc. of Craven in Yorkshire,” by L. C. Miall (1878); “The Fossil Fishes of the Hawkesbury Series at Gosford,” by A. S. Woodward (1890); “Geology of Sydney and the Blue Mountains,” by J. M. Curran (1899).
- HILLIARD, A.—“Refractories and Geology” (1946).
- LEACH, A. L.—“The Rev. G. N. Smith: A Pembrokeshire Antiquary” (1945).
- MASLEN, A. J.—Ten mounted and folded geological maps.
- NEIVA, J. M. C.—“Granitos e jazigos minerais de diferenciacao magmatica das beiras . . . de Portugal” (1945); “Cromste, platina, silicatos nigueliferos e silicatos cobaltiferos em rochas do distrito de Braganca (Portugal)” (1946).

- PLATTEN, G.—*The British Caver*, vols. 14 and 15 (1946).
- PULFREY, W.—“A Suite of Hypersthene-bearing Plutonic Rocks in the Meru District, Kenya” (1946).
- PORTUGAL, DIRECÇÃO GERAL DE MINAS E SERVIÇOS GEOLOGICOS.—*Estudos, Notas e Trabalhos*, vol. ii, fasc. 1 (1946).
- ROYAL SOCIETY OF EDINBURGH.—“The Royal Society of Edinburgh,” by J. Kendall (1946).
- ROGERS, A. W.—Over 180 standard works on geology and about 40 geological maps.
- SHOTTON, F. W.—“Water Supply in the Middle East Campaigns” (1946).
- STOTT, V. H. and A. HILLIARD.—“Variation in the Structure of Zircon” (1946).
- TANGANYIKA TERRITORY, GEOLOGICAL DIVISION.—“Piezo-electric Quartz in Tanganyika,” by B. N. Temperley (1945).
- TREACHER, MRS. LL.—Twelve pamphlets by the late Ll. Treacher.
- UKRAINIAN SOCIETY FOR CULTURAL RELATIONS.—“Geological Structure of the Ukraine,” by V. G. Bondarchuk (1946). (In Russian.)
- WESTERN AUSTRALIA, GOVERNMENT CHEMICAL LABORATORIES.—*Mineral Resources Bulletins* Nos. 1 and 2 (1946) and two other publications.

OBITUARY NOTICES, 1946.

PETER BARNETT was born on the 10th June, 1922. He was educated at Ilford College and Sidcup County School. Entering the Civil Service, he was appointed to the Admiralty and subsequently released for service in the R.N.V.R., becoming a Sub-Lieutenant in August, 1942.

During schoolboy days he was an enthusiastic collector of shells and fossils, at first from the Upper Chalk and the London Lower Tertiaries of North Kent in the vicinity of his home. Later he spent his holidays collecting in the Isle of Wight, from the Thanet Sands of Pegwell Bay and from the Craggs of Suffolk.

Barnett joined the Association in 1939 and his enthusiasm gained him help and encouragement from several members and particularly from the palaeontologists of the British Museum (Natural History), who record that from 1938 to 1942 he presented a number of specimens to the Museum.

Whilst serving in the R.N.V.R., Barnett was stationed for various periods at Gibraltar, Sierra Leone and in the Far East. At each station he must have spent most of his leisure in careful collecting because, from time to time, he sent home collections of land snails, of fossils, and of marine shells. All were exactly labelled as to locality and, in the case of the land snails, detailed notes were added of habitat, climate, etc.

Barnett lost his life in an air disaster when flying from Hong Kong to Saigon in January, 1946. Those who knew him well deplore his loss, not only for his personal qualities, which were high, but because he showed distinct promise of development from keen collector to amateur palaeontologist. His very keenness induced him to take every opportunity to learn all he could about the specimens he collected and, before his studies were interrupted by active service, it was clear that he was preparing himself to specialise in one or two groups of modern and fossil shells. Barnett was just the type that the Association has always welcomed and whose work it has done so much to foster.

[E.E.S.B.]

FRANK NEWBERY GOSSLING, M.C., B.A., died suddenly on the 24th July, 1946. Born in 1888, he accompanied his father on many expeditions collecting fossils in connection with Mr. Gossling, Senior's, work on the Surrey Chalk. Later, a scholar of Emmanuel College, Cambridge, he read geology and, exceptionally, took that subject in the examination for the Higher Division of the Civil Service. Appointed to the Post Office, most of his official career was spent in the Surveyor's Department in the provinces and, at the time of his death, he was Postal Controller for the South-Western District.

In the 1914-18 war Gossling served in the Royal Engineers Postal Service in the Middle East, attaining the rank of Major and winning the Military Cross at Suvla Bay. During the recent war he was, for a time, seconded to the Ministry of Supply, where he served as Assistant Secretary, Establishments Division.

Gossling's duties in the P.O. Survey Department called for much travelling, which suited him well because he used to express his dislike for "desk-work." Thus he could exercise constantly his marked powers of observation when travelling about the country. Two occasions illustrate this habit of a lifetime. In 1923 Mr. Gossling, Senior, was spending a holiday with him and, when motoring across the Brecon Beacons, they stopped for a picnic lunch in a wayside quarry in Old Red Sandstone (Senni Beds). Here they discovered the plant remains which Heard described as "the first recorded occurrence of well-preserved early Devonian plants in England and Wales" ; i.e., *Gosslingia breconensis*, gen. et sp. nov. (*Q.J.G.S.*, lxxxiii, 1927, pp. 195-207). The other example was on the day of Gossling's death ; that afternoon he motored from North Cornwall to Plymouth with two colleagues, who record that it had been a happy journey made interesting by his comments on the geomorphology of the country traversed.

While modestly keeping his own observations in the background, Gossling took a deep interest in his father's geological work, sending him specimens from Egypt for comparative work on wind-blown sand, accompanying him when leave permitted and collecting specimens in Yorkshire, Scotland and elsewhere. He attended the Association's Excursion to the Appleby District in 1907 and occasionally other field meetings, but did not become a member until 1927. He had the warmest regard for the Association's work.

In a few years Gossling would have been due to retire and there is evidence that, but for his untimely death, he would have devoted much of his leisure, as had his father before him, to practical work in our science, for which his capabilities were so well-fitted.

[E.E.S.B.]

By the death of ARTHUR WILLIAM ROGERS, the doyen of South African geology, the Association loses one of its most distinguished members and benefactors. Born at Bishop's Hull, Somerset, on the 5th June, 1872, he was educated at Clifton College and Christ's College, Cambridge, before joining in 1896 the newly-constituted Geological Commission of the Cape of Good Hope. Subsequently, he devoted 36 years of untiring and illustrious effort to Government service, acting as Director of the Geological Survey of the Union of South Africa from 1916 until his retirement in 1932. Under his zealous guidance a large series of valuable geological maps and memoirs was published, and the Union Survey flourished into an organisation of world repute.

Dr. Rogers' own contributions to geological science were numerous and varied, relating mainly to the scene of his life's work in the Cape and Transvaal provinces. His pioneer work on the geology of Cape Colony was followed by detailed investigations in the Kalahari region and the Heidelberg goldfields of Transvaal, and to him we owe the discovery of several glacial deposits in pre-Karoo and probably pre-Cambrian formations. After retiring from official duties he maintained an active interest in the microscopical and microchemical examination of sedimentary rocks, notably the diatomites, until his unexpected death on 23rd June, 1946.

The many honours bestowed on him testify widespread appreciation of his fruitful labours. He was elected a Fellow of the Royal Society (1918), served as President of both the Geological Society and the Royal Society of South Africa, and was President of the XV International Geological Congress at Pretoria in 1929. Among his numerous awards were the Bigsby Medal (1907) and Wollaston Medal (1931) of the Geological Society of London, and the Draper Memorial Medal (1936) of the Geological Society of South Africa.

Dr. Rogers joined the Association in 1921, and shortly before his death he presented to the Library a large collection of geological maps and books, including several rare and valuable volumes, probably the most munificent gift it has ever received.

Sir HAROLD STILES, K.B.E., D.Sc., LL.D., who died at his home at Gullane, East Lothian, on the 19th April, 1946, in his 84th year, was the son of a medical doctor of Spalding in Lincolnshire. Coming to Edinburgh as a student, he graduated in medicine at the University in 1885, and during an eventful life achieved fame as a surgeon, which has made his name and career a legend of the medical world.

Sir Harold Stiles was at one time President of the Royal College of Surgeons of Edinburgh and President of the Association of Surgeons of Great Britain and Ireland, and was an Honorary Fellow of the American Surgical Association. He was a Fellow of the Royal Society of Edinburgh, and a Vice-President of the Edinburgh Geological Society during its centenary year. In 1929 he joined the Geologists' Association, and, with Lady Stiles, took part in the Association's visit to Norway in 1934.

On his retirement, in 1924, from the Chair of Clinical Surgery in the University of Edinburgh, he devoted himself with characteristic thoroughness to the study of natural history, especially geology. He found his chief enjoyment in examining well-known geological sections in various parts of Great Britain, including in his programme a tour of Ireland as well as visits to the Continent. During his journeys he amassed a collection of rocks and fossils, which is unique in that each specimen was obtained for the sake of its

individual value and beauty. The study of the scenery of his adopted country in relation to the geology especially interested him. He had planned the writing of a book with the title *Through Scotland with a Geologist*, but the war intervened and then his physical strength began to fail. Latterly, though his mind remained as resilient as ever, his capacity for remembering detail became impaired. He laid aside his widespread reading in geology and other sciences and took up drawing, learning the technique with the aid of text-books. Several delightful pen-and-ink sketches of natural history subjects were his final contributions to a world in which he had an all-embracing interest, for the world's wonders never ceased to be a source of delight to him. It may indeed be said that he made every moment of his life worth-while.

[J.E.R.]

MIDLAND GROUP FIELD MEETING REPORTS

1. ELLOWS PARK AND TURNER'S HILL

2nd March, 1946

Director : Professor L. J. Wills, Sc.D., F.G.S.

THE party, numbering 32, met at Lower Gornal and proceeded to Mr. Rollason's quarry in the Gornal Grit. The Director announced the discovery by Mr. Rollason of the Downtonian ostracoderm, *Hemicyclaspis murchisoni*, in this sandstone which has always been regarded as a basal member of the Coal Measures, and the recognition of Eurypterid remains in shales now exposed below the grit. These finds appear to make the re-examination of the Gornal Grit an important piece of research. The sections were examined.

The party then proceeded to the new housing site on Turner's Hill and examined sections in sewer trenches which displayed red Downtonian marls, the grey Temeside Beds and Downton Castle Sandstone. Some *Lingula* and Eurypterid remains were found in the Temeside Beds. A stream section in the Red Downtonian and abandoned opencast workings in Coal Measures at Straits Green were also visited.

Before dispersing at Lower Gornal, Dr. Parkinson expressed the thanks of the party to the Director, and Professor Wills replied. The thanks of the party were returned to Mr. Rollason for permission to visit his quarry.

2. DRAKELOW AIRCRAFT FACTORY NEAR KIDDERMINSTER

18th May, 1946

Directors : L. F. I. Walters, L.R.I.B.A., A.M.T.P.I., and Major Thomas.

3. VISIT TO DOVE DALE

5th October, 1946

Director : D. Parkinson, D.Sc., F.G.S.

A 'bus from Birmingham and private cars from various Midland towns took 51 members and friends to the Dog and Partridge Hotel, Thorpe, which was the starting point for a walk into Dove Dale and over some of the surrounding limestone hills.

At the outset the Director gave a very brief account of the geology of the district, mentioning in particular the pioneer work of Dr. J. W. Jackson, who had shown the Carboniferous limestone to belong to the *Caninia* and lower *Dibunophyllum* zones. Dr. Jackson and Professor Fearnside, who also has worked on the Derbyshire limestones, were both present at the meeting, and by contributing their views on some of the outstanding problems, helped to make it a success.

The first exposures to be examined were the limestones of D_1 age in the quarry at the foot of Hamston Hill. These include beds of limestone conglomerate but the junction with the underlying C_2 reef is not exposed.

The climatic conditions were unpromising as Thorpe Cloud was climbed but despite a gale, both cold and damp, almost all the party stayed on the summit to inspect or collect brachiopods and molluscs from the well-known bed at the north end of the ridge. The most characteristic fossil here is *Spirifer bollandensis* which links the horizon (C_2) with that of the Salt Hill-Bellman quarries, Clitheroe.

Exposures of reef conglomerate were examined near the foot-bridge at the entrance to Dove Dale, and between this point and the stepping-stones some of the dips in the limestone were suggested to be original features, not primarily the result of subsequent earth-movement.

The party walked along the Dale, noting the fine cliffs of reef limestone known as the Dovedale Castle and the Twelve Apostles, to Lover's Leap. Between this point and Tissington Spires are bedded black limestones from which Dr. Jackson has obtained specimens of the goniatite *Pericyclus*.

The black limestones were followed for some distance up the hillside east of Lover's Leap where they were seen apparently to pass both laterally and vertically into obscurely bedded reef limestone.

In the depression near the north-western corner of Thorpe Pasture reef breccia-conglomerate considered to indicate slumping, was examined. The overlying cherty limestones appear to have taken part in the slumping. Professor Fearnside expressed the view that the minor contortions they exhibit are not the result of earth-pressure.

Several exposures of fossiliferous D_1 limestone were visited in Thorpe Pasture, the last and stratigraphically the highest, being Pike House quarry, the fauna of which includes *Palaeosmilia murchisoni* and *Goniatites aff. dincklense*.

After tea at the Dog and Partridge Hotel, Prof. Fearnside proposed a vote of thanks to Dr. Parkinson, who in reply expressed his indebtedness to Mr. Parrack and Miss Bauer for organising so successful a meeting.

WHITSUN FIELD MEETING TO THE CENTRAL WEALD

(Weald Research Committee)

8th to 11th June, 1946

HORSHAM was selected as headquarters as members living in London or on the South Coast would be able to join the main party there for individual days. The programme was framed with this idea in view.

HASLEMERE AND MIDHURST

Saturday, 8th June, 1946

Director : Prof. S. W. Wooldridge, D.Sc., F.G.S.

The meeting opened inauspiciously. The weather was very unpleasant. Low cloud, often capping the hills, and almost continuous precipitation, alternating quickly between a gentle drizzle and really heavy thundery rain. To crown everything, the coach bringing the main party from Horsham broke down outside Haslemere. Another was 'phoned for at once and the Secretary then walked into Haslemere to meet the Director and the London party at the station. The day's programme had perforce to be drastically altered. It was decided that Prof. Wooldridge should walk the train party to Fernhurst and that as soon as the "relief" coach arrived, the main party should join them there or at one of the further rendezvous that were arranged.

From a vantage point near Haslemere cricket ground the broad features in the structure and physiography of the area were pointed out. The district is traversed by two east-west anticlinal flexures; the one passing beneath the summit of Hindhead and the other forming the axis of the scarp-rimmed Vale of Fernhurst. The topographic expression of the two folds is thus in complete contrast. Between them is the syncline of the Haslemere valley drained westwards by the Wey. The floor level of this depression at Haslemere is at nearly 500ft. O.D. and the railway, having crossed the Hythe scarp at Witley to descend on to the Weald Clay, climbs steeply again to make use of the col at the head of this branch of the Wey.

A number of tributary valleys descend to the Haslemere trough, following the dip, from both Hindhead and the Blackdown escarpment to the south. The party followed one of these valleys, dry in its upper part, through Valewood Park and then crossed the interfluvium on the western side by a curious "cross-col" near Wadesmarsh Farm. Of this, the Director remarked that he was unable

at present to offer any satisfactory explanation. To say it was due to "erosion" was to utter a truism quite unsatisfying to the geomorphologist. In respect of such erosion it was necessary to ask the questions why? and when? but they could not at present be answered.

The party continued by footpath to Shalford Hill at the head of the large un-named wooded combe, from which a headstream of the Arun drains southwards. At this point the nature of the contest waged throughout the Western Weald between the Arun and its tributaries and the northward flowing drainage was aptly and compactly displayed. The water-parting is here within a short distance of the base of the Hythe Beds along the southward facing scarp of the Fernhurst Anticline. Southwards the affluent of the Arun plunges steeply over the Weald Clay, while northwards, a dry valley, neighbour of the Valewood valley, descends quite gently towards Haslemere. The contest at the water-parting has been biassed further in favour of the Arun by the drying up of the Wey affluent on the Hythe Beds. Generally, however, the advantage of the Arun lies in the proximity of the sea at Littlehampton, compared with the long route which northward flowing water must traverse via Weybridge to the mouth of the Thames. Each recent phase of rejuvenation has graven itself deeply in the Arun country, but time has not sufficed to bring similar waves of back-cutting to the headwaters of the Wey.

The party continued its walk via Copyhold Hill to the main road above Fernhurst village, following a line close to the base of the Hythe Beds and one followed by what appears to have been an old pack-horse track ante-dating the turnpike roads and their successors. After lunch at Fernhurst, the main party arrived in a "relief" 'bus, bringing the total number of the party to 21, and the planned afternoon programme was begun, though it was hindered by heavy rain.

A visit was first made to road-cuttings, resplendent with rhododendrons, at Hollycombe which reveal the fine grained sands and cherty sandstone beds near the base of the Hythe Beds. Thence the Fernhurst Vale was crossed to the Plough Inn at Redford. The scattered hamlet of Redford lies in a conspicuous gap in the northward facing escarpment between Telegraph Hill and Dunner Hill. On the west side of the gap the beds seem to be in a normal and undisturbed attitude, but between the Plough Inn and the summit of Telegraph Hill there is a tract of complex and broken ground underlain by slipped masses of Hythe Beds well below their true level. The slipping has taken place not on the scarp-face, but on the steep westward facing side of the gap. There appear to be three or four distinct slipped slices. Of these only the most easterly is well-exposed. A conspicuous "gulch" followed by a track lies immediately east of the trigonometrical pillar and well displays

the steeply dipping Hythe Beds, broken away at a higher level and "rotating" on the way down in accordance with the curvature of the slip plane. The phenomenon is common throughout the Weald and an example was minutely described by the late Mr. F. Gossling at Bower Hill near Nutfield [1*]. The Director pointed out that the present case showed two special features of interest. In the first place, it would appear that the slipping is of considerable antiquity, for a combe-like valley head has been eroded across the slipped masses since they were emplaced. The individual slices can be matched on both sides of the combe. Mr. Brian Gossling, who was a member of the party, called the Director's attention to a further fact with a possible bearing on the age of the slips. According to the Director's mapping the composite slipped mass projects northwards considerably beyond the line of the escarpment at Telegraph Hill. This may well give a measure of the subsequent recession of the escarpment; for, except on the assumption that the scarp was further forward at the time of the slipping, it is difficult to see where the northern extremity of the slip-complex came from. The second feature of interest is the possible effect of the slipping in initiating or assisting river-capture. The floor of the Redford Gap is raised so little above the Weald Clay country to the north that at first sight it would be taken as a functioning water-gap. In fact it is a wind-gap, the stream draining southwards from Stedham Marsh having been beheaded by a branch of its western neighbour. This involves a reversal of the normal order of capture in such a case, for rejuvenation proceeding upstream from the Arun trunk would reach the mouth of the Redford stream before that of its western and therefore *upstream* neighbour. Any one of a number of slight deranging factors might bring such trifling "inversion" about, but one possible and even likely cause would be the partial blocking of the gap by considerable landslips, thus reducing the effective supply of water from the lowland beyond, if not temporarily damming the stream. The ground is so heavily covered with heath vegetation that it is difficult to define the original size of the slipped masses; it is manifest at least that their lower parts have suffered considerable erosion.

On rejoining the 'bus the party travelled southwards down Woolbeeding Lane and so via Stedham to the main Midhurst road, pausing briefly to admire the incised meander of the Rother at Stedham and to note roadside exposures of the Bargate Beds. After tea at the Spread Eagle Hotel, Midhurst, the party returned by road by Petworth to Horsham, visiting en route roadside exposures in the Selham ironsands of the Sandgate Beds and noting the strong local reversal of dip brought about by a minor anticlinal roll, which is traceable for some miles roughly in the latitude of

* For List of References see p. 85.

Midhurst. At this, the last halt, Dr. A. J. Bull expressed the thanks of the party to the Director.

CENTRAL WEALD

Sunday, 9th June, 1946

Director : P. Allen, M.A., B.Sc., Ph.D., F.G.S.

Fifteen members met at Three Bridges Station, where the Director explained that the chief aims of the day were to make (1) a general examination of the succession and structure of the Lower Wealden rocks in the Central Weald, and (2) a more detailed comparison of the strata at the junction of the Grinstead Clay and Lower Tunbridge Wells Sand with those at the junction of the Wadhurst Clay and Ashdown Sand. The outward journey would trend mostly parallel to, and against, the axial pitch of the Wealden anticlinorium, and successively older strata would therefore be observed during the earlier part of the day.

The Upper Tunbridge Wells Sands south of Three Bridges were crossed and a halt made at the mile-long road-cutting south of Balcombe (B 2036). This exposed an almost complete sequence from the ferruginous loam at the base of the Upper Tunbridge Wells formation, through the underlying Grinstead Clay, to the sandy top beds of the Lower Tunbridge Wells Sand. The Balcombe *Equisetites lyelli* Soil-Bed [2] stimulated much comment, and a wealth of material was collected. The Director pointed out the local nature of the bed, the gley-like (rust-mottled) appearance of its matrix, its practically uneroded top, the complete dominance of one species and the compressional features of the plants. Beneath the soil-bed, 10ft. or more of alternating thin shales and light current-bedded siltstones (lenticular) were examined, and farther south the underlying dark ostracod-shales yielded *Unio antiquus*, *Neomiodon* spp. and *Viviparus* spp. Arriving at the knoll formed by a slight anticline one mile south of Balcombe, members were able to see, in a sandpit at that place, the downward transition to siltstones which overlie the symmetrically rippled top surface of the Lower Tunbridge Wells Sand.

This uppermost layer included a ferruginous grit containing rare pebbles of quartz, chert, etc., and, at the south end of the pit, an abundance of comminuted scales, teeth and fin-rays of *Lepidotus* and *Hybodus*. Though seldom attaining an inch in thickness, it clearly represented the Top Lower Tunbridge Wells Pebble Bed well known at West Hoathly [3] and elsewhere. Through the fortunate presence of an upturned bath and plenty of straw to kneel upon, the members were able to examine through a petrological microscope in comparative comfort prepared mounts

of the "light" and "heavy" residues of the pebble bed. It was noted that the allogenic suite of the matrix comprised quartz, clay, glauconite, zircon, black iron ore and leucoxene, rutile and tourmaline, together with scattered grains of felspar, muscovite, garnet, staurolite, and a few other minerals.

A detailed statistical study had been made of the lateral distribution of the various minerals in this stratum, and it was found that the quantities of zircon, black iron ore, rutile and tourmaline varied sporadically from place to place. The actual *amounts* of their variation, however, were related in a characteristic way to the area of exposed bed that could be sampled [4]. The hydraulic implications of this will be dealt with more fully in a forthcoming paper.

A close relationship had been found to exist between the coarseness of the heavy allogenic fraction and the proportion of garnet, apatite, staurolite, kyanite, and sillimanite present in it. Garnet and apatite were usually most abundant in the localities where the heavy fraction was of "medium" grade; staurolite, kyanite, and sillimanite on the other hand became progressively more abundant in the coarser facies. Statistical work has shown that these results are not fortuitous. The Director pointed out that at Balcombe, where the zircons were of "upper medium" grade, small quantities of garnet, apatite, staurolite, kyanite, and sillimanite were present; but at West Hoathly, where the zircon size is "medium" grade, garnet and apatite become more abundant, and staurolite, kyanite and sillimanite are even rarer than at Balcombe.

A move was then made eastwards to a moderately "coarse" facies in the heavy fraction of the Top Lower Tunbridge Wells Pebble Bed, at Shortbridge. The lack of garnet and apatite and the appearance of more staurolite were duly observed. The pebble bed rested on a hummocky surface of white sandstone, and was seldom more than $\frac{1}{4}$ in. thick. It was ferruginous, minutely current-bedded, and contained a high proportion of zircons—possibly due to concentration by long-continued "panning." The rarity of pebbles was noted, and it was pointed out that there was often no direct relationship between the grade size of the matrix and that of the pebbles.

After brief visits to a cutting lower down in the Lower Tunbridge Wells Sand at Founthill, Newick (yielding pebbles of quartz, quartz-veined pink quartzite, black chert, grey chert and oolitic chert) and to Piltown Common (where Dr. A. J. Bull discoursed on the finding of *Eoanthropus dawsoni*), the party was whisked away to the heart of the Heathfield-Brightling anticline, a convenient hostelry, and a very welcome lunch.

Early in the afternoon, the journey was continued along the southern flank of the anticline to the outlier of Wadhurst Clay south of Dallington. Here, at the eastern extremity of Hoads

Wood, the strata at the Wadhurst Clay-Ashdown Sand junction were fully exposed (see [5], fig. 57A). The striking similarity to the newer beds seen in the morning was noted immediately, the Director explaining that, for mapping purposes, the only constant distinctions lay in the presence of the Brede *Neomiodon medius* Shell Bed and the Brede *E. lyelli* Soil Bed towards the base of the Wadhurst formation.

After collecting from the basal Wadhurst, the members concentrated their attention on the top Ashdown strata. The glauconitic and highly ferruginous Top Ashdown Pebble Bed—up to 4 ins. thick, symmetrically rippled above, and minutely current-bedded—was seen to be coarsest at the base. It yielded pebbles of quartz, chert and oolitic chert, and lay with marked discontinuity on a relatively flat surface of white glauconitic sandstone, overstepping the local false-bedding in the latter. The members were particularly struck by the large size and extreme beauty of the heavy detritals—in particular by the ruby-like rutiles and the big staurolites, kyanites and sillimanites observable without microscope or lens. It was explained that detailed areal study of the pebble bed (and also of the sandstone) had disclosed a similar mineral assemblage and similar relationships [6] to those existing in the Top Lower Tunbridge Wells Pebble Bed. The grade size pattern of the matrix was found to be marked by three areas of coarse sediment elongated N.E./S.W. and running from Buxted to Lamberhurst, Bodle Street to Udiam, and Hastings to Playden. They were separated by medium facies in the south-east Weald and by successively finer facies north-westwards. The frequency-contour patterns of garnet and apatite were therefore “streaked out” in a N.E./S.W. alignment, and formed “negatives” of those of staurolite, kyanite and sillimanite. The present pit, being in the centre of a “coarse” area, yielded abundant staurolite and some kyanite and sillimanite from the pebble bed, but virtually no garnet or apatite. The distributional patterns were considered to indicate north-easterly and/or south-westerly movements of heavy accessories. Such a conclusion appeared to be supported by (1) the false-bedding of the top Ashdown sands, (2) the ripple-marking on the Top Ashdown Pebble Bed, (3) the N.E./S.W. distribution of the subsequent Brede Bone-Bed [4], (4) the N.E./S.W. trend of the eroded margin of the subsequent Brede *E. lyelli* Soil-Bed (5, fig. 57B, and 1, fig. 1), and (5) the N.E./S.W. margin of the eroded area of the subsequent Brede *N. medius* Shell Bed. Furthermore, the thickness of Basal Wadhurst Siltstones and Shales (here 9½ ft.) varied systematically in the Central and South-east Weald, resulting in an isopachyte distribution closely simulating that of matricial grade in the Top Ashdown Pebble Bed. The thickest developments of basal Wadhurst beds thus overlie the coarsest Ashdown facies. Consequently, if the soil bed be accepted as a reliable datum of original horizon-

tality, the thickest developments were originally sited in shallow hollows elongated N.E./S.W.—presumably the scour-grooves of faster currents. As in the earlier pebble bed, the pebble grade varied antipathetically to that of the matrix. There was a noticeable increase in mean pebble grade northwards across the Weald, and south of a line from Waldron to Brays Hill the pebbles failed altogether. Apparently some sediment deficient in garnet, apatite, staurolite, kyanite and sillimanite came with the pebbles, for north and north-west of this line the frequencies of these minerals decrease independently of grade.

The lateral variation observed in these thin horizons appears to account for the whole of the vertical variation known within the Lower Wealden of the area.

Replying to questions, the Director drew a close comparison between the cycles of sedimentation represented by the two pairs of formations. He added that the majority of the horizons seen during the excursion were almost certainly not coincident with time-planes, but represented transgressive environmental facies of two advancing deltaic fronts.

Driving across the Purbeck rocks to the north flank of the anticline at Burwash, the party then visited the Wadhurst Clay-Ashdown Sand junction on Kings Hill. Centred in a tract of "medium" matricial grade, this exposure of the pebble bed yielded plenty of garnet and apatite, but no staurolite, kyanite or sillimanite. As was to be expected, the pebbles were more numerous than at Dallington, and the overlying siltstones and shales were reduced in thickness ($6\frac{1}{2}$ ft.).

From Burwash the return journey was made via the Ashdown Forest anticline and East Grinstead. Tea was had at Felbridge, where Dr. A. J. Bull proposed a vote of thanks.

After tea, the East Grinstead Soil-Bed was demonstrated at Coombe Hill [2], and the Upper Tunbridge Wells Sand at Turners Hill. From the latter viewpoint the North and South Downs became sharply clear for a moment, and shafts of sunlight in a stormy sky lit up the wooded ridges between. We left the Central Weald in all her glory.

STORRINGTON TO PETWORTH

Monday, 10th June

Directors : A. J. Bull, Ph.D., F.G.S. and J. F. Kirkaldy, D.Sc., F.G.S.

A party of 19 assembled at Horsham Station and then proceeded by coach along the Worthing road. A brief stop was made by the cricket ground to indicate the prominent feature,

capped by Horsham Stone, running through Denne Park. For some 10 miles the very gently undulating country on the outcrop of the Weald Clay was traversed, until near Ashington the low escarpment formed by the Lower Greensand was reached. Brownish ill-graded slightly pebbly sands were examined in a roadside exposure near Rock. The Director (J.F.K.) said that these were typical of the rather monotonous Folkestone Sands of Sussex, which did not contain any of the minor lithological units, such as silt bands and silver sands, traceable in the Folkestone Sands of Surrey.

The coach then turned westwards to the fine exposure of Folkestone Sands and Gault at the Marley Tile Co., near Chantry Mill, Storrington. This pit has been extended since it was last visited by the Association and is by far the best section for examining the "Iron Grit" [9]. Dr. Kirkaldy described the relationships and mode of origin of this peculiar local basal bed of the Gault and some time was spent in examining the section, but no fossils were forthcoming and the exact horizon of the overlying Gault clay still remains unknown. Dr. Bull then described the white flint drift, which capped the section. It consists of chipped and broken flints set in a sandy matrix. None of the flints are waterworn, they all have sharp unworn edges produced presumably by freeze-and-thaw conditions. They could, therefore, only have reached their present position from the Chalk escarpment by sludging, before the present vale between it and the Downs was eroded. The little hill into which the pit is cut rises just above the 200ft. contour, as do many similar drift capped hills fringing the Downs on the north. These hills are remnants of the 200ft. platform and the white flint drift can, therefore, be correlated with the Great Chalky Boulder Clay, which overlies the 200ft. platform to the north-east of London.

Pleasant lanes were then followed across the various members of the Lower Greensand to the centre of the Greenhurst anticline just south of Abingworth. After the Fernhurst anticline, so dimly glimpsed through the murk on Saturday, the Greenhurst anticline and the complementary Warminghurst syncline afford the clearest case of "inverted relief" in the Weald. The scarp and dip slopes of the Hythe Beds were used to demonstrate the structural features, whilst the detailed lithology of the Hythe Beds and their passage into the overlying richly glauconitic loams of the Sandgate Beds was examined in the fine section at Jackets Hill [9, p. 74].

After lunch in Storrington, the coach proceeded to the entrance of Arundel Park at Whiteways Lodge. The party then walked for about a mile along the edge of the gap the river Arun has cut from north to south through the Chalk of the South Downs. The sky was overcast, but visibility was excellent; very different conditions for Dr. Bull's description of the view, from those of 28th May, 1938, when the Association last visited this spot.

Looking across the river gap the view comprised the whole width of the Downs from Kithurst and other hills forming the escarpment, down the dip slope to the coastal plain on the south, out of which rises the Chalk hill of Highdown. Two features of the view were clearly seen, the dry valleys, some of which open into the gap, and the so-called second escarpment, a series of hills midway down the dip slope, and of them Wepham Down, Harrow Hill, and the distant Cissbury Camp were in view. These hills are separated by dry valleys, and they consist of Chalk of the zone of *Offaster pilula* with *Marsupites* Chalk exposed round their lower slopes.

In the gap the river has incised itself and formed a set of river cliffs with complementary spurs coming out from the opposing sides. The spurs are flattened and show relics of old terraces, while below these the gentle slopes are indicative of ingrown meanders. The chief terrace seen was the 130ft., which is the same height as the upper part of the neighbouring Goodwood Beach. The bottom of the gap is flat, and the marshy alluvium occupied a deep buried channel, which was cut at times when the sea-level was much below its present level.

Northwards was seen the village of Amberley built on the Upper Greensand escarpment, and immediately north of this is Amberley Wild Brooks, where the Gault has been eroded in a continuation of the buried channel and forms an extensive area that is often flooded. Beyond this the scenery is dominated by the Greenhurst Anticline which pitches westward, and so brings higher members of the Lower Greensand to the surface as one follows the axis westward. The party had earlier in the day seen the opposing Hythe escarpments near Greenhurst Farm, and in the present view there was the wooded outcrop of the Sandgate Beds at Northpark Wood and west of the river the few houses at Coldwaltham where the Folkestone Sands are exposed. The cuesta formed by the Hythe Beds could be seen to be appreciably higher on the western side of the gap cut by the river Arun; whilst on the western side the dip slope was wooded, on the eastern side it was under arable cultivation. This reflects the change in the lithology of the Hythe Beds, from a calcareous facies on the east, similar to that seen at Jackets Hill, to an arenaceous facies on the west.

Finally, Mr. E. C. Martin described the features of the coastal plain and the evidence for Highdown Hill having been a promontory at the time of formation of the Goodwood Beach.

On rejoining the coach, the face of the Chalk escarpment was descended at Bury Hill and the outcrop of the Gault was crossed to Fittleworth. A convenient "pull in" was provided by the pit just below Hesworth Common. Dr. Kirkaldy stated there that the Sandgate Beds of the south-west Weald could be divided into the

following lithological units : the Marehill Clay underlain by the Pulborough Sand Rock, then a considerable thickness of loams and finally at the base the Bargate Beds, which were identical in lithology with the Hythe Beds of Jackets Hill. The typical lilac to red coloured loams with abundant glauconite grains often oxidised to limonite, were examined in the pit and nodules of fossiliferous ironstone yielded *Thetironia minor* (Sowerby) and *Corbula striatula* Sowerby. Hesworth Common was then ascended and the features of the extensive view described [8, p. 28]. A path leading north-eastwards was then followed to the top of the cutting on the Petworth road. A belt of swampy ground, just above the road, was seen to be due to the blackish, blockily weathering, Marehill Clay, whilst the main part of the cutting was through the Pulborough Sand Rock, which at first sight might be mistaken for a part of the Folkestone Sands. It differs from them, however, in its very uniform development of some 30 feet of fine-grained yellow sands and silts.

The Petworth Road was then followed and a last stop was made at the sharp bend west of Little London to examine the arenaceous facies of the Hythe Beds. Unfortunately the pit to the north of road, opened shortly before the War, has been filled with rubbish, so the party followed the track leading eastwards to the old and now badly overgrown pit. The section showed some 20 feet of yellowish, knottily weathering fine-grained sandstone, gently flexured along east to west axes. These beds underlay the main development of cherts, which it had been hoped to examine, but blocks of massive bluish chert, up to one foot in thickness, could be found at the sides of the track.

During tea at Petworth, Mr. E. C. Martin proposed a vote of thanks to the Directors and mentioned appreciatively Dr. Kirkaldy's services as Secretary for the Field Meeting. The coach then returned to Horsham via Wisborough Green and Billingshurst.

THE HENFIELD NEIGHBOURHOOD

Tuesday, 11th June

Director : Rev. J. W. Reeves, M.Sc.

Nine members assembled at Henfield Station. The Director, who had been responsible for working out the detailed structure of the area in connection with the deep boring put down near Ashurst by the D'Arcy Exploration Co. Ltd., described the day's traverse, illustrating his remarks by a series of sections on the scale of 6in. to the mile.

The two major geological structures to be crossed were the Henfield Syncline and further south the Pyecombe Anticline. The shape and size of the Henfield Syncline was shown on the first section—which was true to scale—and the steeply dipping northern limb, which quickly flattened to the north and to the south was noted. The marked flattening of dip traceable in the cutting to the north of Henfield Station, was regarded as due to a monoclinical flexure which was the eastward termination of the Greenhurst Anticline visited on the previous day. The steeply dipping beds were well exhibited in the small pit in the Hythe Beds, at Coombe Croft, about a quarter of a mile north-west of Henfield Station. Here a maximum dip of 30 degrees south was recorded, but the slackening of the dip towards the synclinal axis to the south was already beginning to appear in parts of the pit.

The party then proceeded past the Station to Nep Town, noting small seepages where the junction of the Sandgate Beds and the Folkestone Sands was crossed. At Nep Town a large pit in the Folkestone Sands was visited and Dr. Kirkaldy pointed out the similarities to the sections which had been seen on the previous day. On the western side of the pit there was an indication of a northerly dip, showing that the axis of the Henfield Syncline had been crossed. Good views of the scarp formed by the Lower Greensand which, except in the extreme north-west, entirely surrounds the Pyecombe Anticline, were seen. The lane down this scarp was then followed and even in the short distance before the Weald Clay was reached, the differing effects of the Lower Greensand members were noted. The help given in detailed mapping by the vegetation, particularly holly, which flourishes on sand, and rushes, which thrive on the wetter clays, was explained.

Noting the general change of topography as soon as the Weald Clay was reached, the party proceeded to the Henfield Brickworks, where good examples of Paludina Limestone (Sussex Marble) were examined. The use of this rock for decoration particularly in some local churches was mentioned. It was pointed out that the Paludina Limestone in this area was not a good mappable horizon—it *can* be followed by means of the debris with difficulty for short distances—but in the main it was more a series of lenses at approximately the same geological horizon than a continuous bed. The five degree dip, to the north, of the clay in the excavations was noted.

Following the road from Henfield to Small Dole the position of the axis of the Pyecombe Anticline was pointed out, as well as a distinctive bed of red clay, well exposed in the ditch just south of Woods Mill. This bed, so distinct from the mass of yellow clay above it, could and had been “walked” round most of the anti-clinal area, and, as a readily mappable bed, had been chosen as an

index horizon. Detailed mapping had shown that the Weald Clay of the Henfield neighbourhood could be divided into the following units in downward succession :—

Group III (Yellow), some 350 feet of stiff yellow (blue when freshly exposed) clay.

Group II (Variegated) about 820 feet of coloured clays, shales, shelly and other limestones and sandstones.

Group I (Buff) not exposed near Henfield. Thickness near Horsham about 140 feet.

The red clay mentioned above formed the boundary between Groups II and III. The total thickness of the Weald Clay in the area had been estimated to be 1,310 feet. Fossils were scarce, although there were occasional beds with abundant ostracods and a few lamellibranchs.

Lunch was taken at Small Dole and the party then proceeded rapidly to Beeding to catch a 'bus to the Washington-Ashurst road junction just north of Steyning. Several interesting pits and morphological features to the south of Small Dole, described in earlier reports [10], had to be passed with but a fleeting glance.

After walking, from the road junction, across the outcrop of the Gault towards Ashurst, a halt was made by the sharp bend near West Winds Poultry Farm to visit a small pit, now badly degraded, which showed the junction of the Gault and the Folkestone Sands. Dr. Kirkaldy pointed out that the junction was of normal character with phosphatic nodules, contrasting strongly with the Iron Grit seen on the previous day at Storrington. Unfortunately the excellent section in the road which used to show a southward dip of 10 degrees, was now completely overgrown. The features formed by the various members of the Lower Greensand were indicated and the scarp formed by the Hythe Beds, very well exhibited, was crossed.

A little way to the north, recent ditching in one of the fields showed the index bed of red clay extremely well, and the party were able to see how strongly it stood out against the general yellow clay to the south.

The main item of interest in the afternoon was the visit to the site of the test well, between Calcot and Northover Farm and $1\frac{1}{2}$ miles S.S.E. of Ashurst Church, put down in 1936-7 by the D'Arcy Exploration Co. Ltd. [11]. Much to the surprise of some members of the party, this was completely hidden, but the Director explained that there was no need for misgivings that oil production in England was likely to spoil the amenities of the countryside. Once drilling had ceased and the derrick had been removed, but a small portion of land was needed and a few well placed trees could entirely hide the site. This led to a discussion of drilling methods and a description of the rotary method used in the test well was given. The

means of collecting the "cuttings" and their washing and examination was touched upon and some of the former from the old heap were examined. Suggestions as to their geological age were very tentatively made.

The party then proceeded over the northern limb of the Pyecombe Anticline to the steep scarp made by the Hythe Beds, which, well exposed in the road cutting, were dipping north at about 18 degrees. These beds were the only representatives of the Lower Greensand in this pitching end of the Henfield Syncline; within a mile or so to the west the effect of the syncline had ceased.

Whilst waiting for the coach to take the party to Henfield for tea and then on to Horsham, Dr. Bull proposed the vote of thanks.

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THE GEOLOGY OF THE EVENLODE GORGE OXFORDSHIRE

By W. J. ARKELL, M.A., D.Sc., F.R.S.

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I. INTRODUCTION

THE streams forming the headwaters of the River Evenlode rise on drift-covered Lower Lias at an elevation of about 450ft. O.D. around Moreton-in-Marsh. The river flows S.S.E. down the Vale of Moreton for $10\frac{1}{2}$ miles to Shipton-under-Wychwood, where it turns a right-angle to flow E.N.E. for four miles, then curves round (still on Lias) to resume its original direction near Charlbury, where it enters the gorge through the Lower Oolites. The gorge is about six miles long. The upper half is straight, but the lower half consists of a series of large incised meanders, for which the Evenlode is famous in physiographical literature (W. M. Davis, 1899, 1909). After leaving the gorge the river flows comparatively straight for the last $2\frac{1}{2}$ miles over Oxford Clay. It joins the Thames near Eynsham, shortly after crossing the 200ft. contour.

The total fall of the river is, therefore, about 250ft. in its course (omitting meanders) of about 25 miles ; but since the 400ft. contour is crossed within a mile of Moreton-in-Marsh, the effective gradient is 200ft. in 24 miles, or 8ft. 4ins. per mile. In the six miles of gorge the fall is 60ft., or 10ft. per mile, the average gradient of the rest of the river being, therefore, only a little over $7\frac{1}{2}$ ft. per mile.

Along the sides of the gorge the whole Great Oolite Series and the Inferior Oolite are exposed in a succession of railway-cuttings and quarries, and puzzling structures are developed in these rocks and the underlying Lias.

Above and below the gorge are important spreads of terraced Pleistocene gravels of the Evenlode ; within it run rock-platforms with here and there residual patches of gravel ; and on the hills on either side are remains of a mantle of Northern Drift.

The lower end of the gorge was included in the 1-inch Oxford Special Sheet (1908) of the Geological Survey, and most of it in

the Witney sheet (1938), but neither map includes the bend of the valley above Charlbury, with its important gravel deposits and structures ; this area has not been revised since the Old Series map of 1859 (sheet 45 S.W.). The Witney memoir, by L. Richardson and H. G. Dines, although in proof before war broke out, is not yet published and has not been seen by me (excepting the Upper Jurassic and Lower Cretaceous chapters, for which I was responsible, but which contain nothing relevant to the present enquiry). Mr. L. Richardson and Mr. H. G. Dines have, however, kindly provided me with information on several points.¹

Six-inch mapping of the gorge and the Lias funnel up to Kingham was undertaken with the following objects :—

1. To establish the stratigraphical and topographical importance of the subdivisions of the Great Oolite Series pieced together from the cuttings and quarries along the sides of the valley (Arkell, 1931, pp. 610–615) ; and to determine how far the stratigraphy is responsible for rock-platforms which might be attributed to river-action.

2. To investigate the syncline which the Evenlode is said to follow (Pocock, 1908, p. 107 ; Spicer, 1908, p. 341), and to elucidate anomalous structures in the Jurassic rocks exhibited at several places in the gorge and alluded to, but not explained, by Hull (1859, p. 9), Bather (1886, p. 143), and Pocock (1908, p. 10). In addition to these recorded anomalies, there are others no less remarkable, including nearly vertical strata at three places.

3. To link up the Pleistocene terraces below the gorge and in the upper Thames valley, described by Pocock (1908) and Sandford (1924, 1926, 1929), with the terraces and glacial drifts of the Vale of Moreton, described by Tomlinson (1929) and Richardson and Dines (1929). On this correlation hangs much of importance for British Pleistocene classification. My offering towards its achievement is four years' experience of mapping the similar terraces and gorges of the Nile with Dr. K. S. Sandford.

For information or for help of various kinds I am indebted to Mr. D. F. W. Baden-Powell, Mr. H. G. Dines, Professor J. A. Douglas, Mr. F. H. Edmunds, Professor S. E. Hollingworth, Dr. H. C. Jennings, Dr. K. P. Oakley, Mr. L. Richardson, Dr. K. S. Sandford, Dr. Mabel E. Tomlinson, Mr. H. J. O. White, Mr. T. H. Whitehead, and Professor L. J. Wills.

II. THE JURASSIC ROCKS

(See the vertical column on Plate 3, facing page 114)

Lias. Owing to paucity of exposures the Lias within the area of the map shows little of interest stratigraphically, except at Fawler.

¹ See postscript note on p. 112, below.

The old ironstone quarries here were described when in better condition than at present by Bather (1886) and other authors ; below the Clypeus Grit was exposed 5–11ft. of Upper Lias, 9ft. of Middle Lias ironstone, and at least 11ft. of Middle Lias micaceous loamy sands ; Lower Lias with *Ammonites capricornus* was worked in the old brickyard. A similar section, from the micaceous loams (here containing sandstone doggers) up to the Clypeus Grit can still be seen in the railway-cutting and lane-cutting south of Fawler, figured by Hull (1859, p. 9). Since the Upper Lias clay was proved to be 31ft. thick in a boring (1934) at Waterman's Lodge, Wychwood Forest, only $2\frac{1}{2}$ miles to the west, and is still 14ft. thick under Wytham, near Oxford, it is probable that the thickness of only 5–11ft. at outcrop at Fawler is due to reduction by washing out at the spring-line (and/or squeezing ?) (see below, p. 95).

In the funnel of the gorge near Charlbury, Lower Lias with *Ammonites planicostatus* was said to have been exposed in the railway-cutting, presumably the one close to the station (Horton, 1860), and doggers of micaceous sandstone like those in the Middle Lias at Fawler can still be seen farther north in the same cutting, at Walcot. The Middle Lias ironstone has never been worked above Charlbury, where it is much thinner than at Fawler. It is exposed at two places in the banks of the Evenlode : on the right bank, 40yds. below Catsham Bridge (as noted by Bather, 1886, p. 145), and on the left bank 600yds. above and due west of Catsham Bridge. At both places it is only 1–2ft. thick.

Both these exposures of the top of the Middle Lias above Charlbury are in the middle of the tract coloured as Lower Lias on the Survey maps (Old Series, Sheet 45 S.W. and Index Sheet 15), and the downfaulted tract shown on these maps in the valley west of Spelsbury appears to be explicable only on the assumption that river gravel of the Spelsbury terrace was mistaken for an outcrop of Clypeus Grit, fragments of which abound in the gravel. Like Bather (1886, p. 145) I could find only clay all over this area, from the Clypeus Grit down to the gravel or the river bank. It seems probable that the Middle Lias crops out only in the bottoms of the deep stream valleys below Dean and Spelsbury (see Hull, 1859, p. 9) and in a fringe close to the Evenlode, mainly obscured by gravels. For this reason all the Lias outcrop is shown by one colour on the accompanying map (Plate 3). The alternative possible structural interpretations of the evidence are discussed below (p. 96). At least as far upstream as Milton-under-Wychwood and Fifield the line drawn for the base of the Middle Lias on the Survey map (Witney sheet, 1938) coincides approximately with the base of the Clypeus Grit, and any separation of Upper and Middle Lias in the clay vale below would be purely hypothetical.

Inferior Oolite and Great Oolite Series. It is well known that in this district there is a large disconformity between the Upper Lias and the thin representative of the Inferior Oolite, which consists solely of the highest beds, the Clypeus Grit (normally about 35ft. thick) and some limestones of the age of the Zigzag Subzone (Richardson, 1910).

In Oxford University Museum there are six ammonites from the Clypeus Grit of Fawler. Three of them I identify as *Parkinsonia depressa* (Quenstedt), and two as *P. parkinsoni* (Sowerby), and one is a very large smooth form apparently identical with *P. densicosta* (Quenstedt) as figured by Nicolesco (Pl. 9, Fig. 1). During the present survey I also obtained a fragment of *P. depressa* (Quenstedt) from the Clypeus Grit of Charlbury cemetery. (The name *depressa* Quenst. sp. as now used includes the form figured as *Parkinsonia schloenbachi* Schlippe by Buckman, but none resembles Schloenbach's figure of the type).

Above the Clypeus Grit follows the Chipping Norton Limestone, normally 23ft. thick (see Table I). The term is used here in a comprehensive sense as employed by Hudleston and by Richardson, because the formation cannot usually be subdivided in the field, except where clearly exposed. It was shown by Walford (1883, p. 237), however, that around Chipping Norton and Hook Norton the lower half, up to and including the *Trigonia signata* Bed (alias Knotty Bed or Old Man), contains Parkinsonids and belongs to the Inferior Oolite, while the upper half contains only fossils of the Great Oolite series. Walford's observations have been confirmed by the finding at Workhouse Quarry, Chipping Norton, by Dr. H. C. Jennings, Prof. J. A. Douglas, and myself, of ammonites of the Zigzag Subzone, which from their matrix certainly came out of the *Trigonia signata* Bed and beds below, which Walford separated under the name Hook Norton Limestone. My identifications of these large and well-preserved ammonites are: *Parkinsonia eimensis* Wetzel, *P. cf. neuffensis* (Oppel), *P. depressa* (Quenstedt) cf. var. *crassa* Nicolesco, *Procerites subprocerus* (Buckman), *Procerites pseudoprocerus* (Buckman). This quarry (Arkell, 1947, p. 32) is less than three miles beyond the N.W. edge of the present map. I also found *Parkinsonia* sp. at Fulwell Quarry.

In the area of the present map the separation of Hook Norton from true Chipping Norton Limestone is hardly possible with existing exposures. A bed full of *Trigoniae* seen in section, which seems to be the *Trigonia signata* Bed, with 5ft. of limestone above and below, is exposed at a pond 500yds. S.S.W. of Hillbarn Farm, $\frac{5}{6}$ mile W.N.W. of Stonesfield Church. At sections in the Evenlode valley, however, the *Trigonia signata* Bed has not been identified, and it cannot be said with certainty that any Hook Norton Beds are represented. The best exposure (1946) is a quarry half a mile N.E. of Charlbury Church, in the fork of the Ditchley Road and

a lane, where a small (artificial) inlier of Clypeus Grit is shown on the map :—

QUARRY ON THE DITCHLEY ROAD, CHARLBURY

	ft.	in.
CHIPPING NORTON LIMESTONE		
7. White oolitic limestone, weathering slabby	9	0
6. Brownish sandy oolite, more massive bed, 2ft. 2in. to ...	2	6
5. <i>Terebratula</i> and <i>Ostrea</i> bed : marl and marly limestone, 2 to 10in.		6
4. Limestone, compact, hard, brown, not oolitic	1	8
CLYPEUS GRIT		
3. Coarsely oolitic cream limestone	2	8
2. Coarsely oolitic rubble, full of the usual fossils of the Clypeus Grit	2	0
1. Limestones, hard, buff, only here and there oolitic ; in three beds	3	0

The *Terebratulids* in Bed 5 are an undescribed form. Dr. H. M. Muir-Wood informs me that she is unable to match them with any from the Clypeus Grit. The oysters likewise have not been definitely identified, but the fragments collected suggest the presence of *O. hebridica* Forbes, *O. subrugulosa* Morris and Lycett, and *O. wiltonensis* Lycett, all Great Oolite forms.

Neither the *Trigonia signata* Bed nor the *Terebratula* Bed of the Ditchley Road quarry has been identified in the big old quarries N.E. of Charlbury (out of which most of the town was built), or at Buckleap Quarry in Cornbury Park (out of which were built the mansion of Cornbury and parts of Clarendon House, Piccadilly : Watney, 1910, p. 4), or in the old ironstone quarry at Fawler, or in the railway-cuttings S.E. of Charlbury Station. At all these places it is possible that the Hook Norton Limestone is overlapped more or less completely by the Chipping Norton Limestone proper.

From the Chipping Norton Limestone as restricted by Walford (the upper half of the formation in Richardson's sense) *Oppelia fusca* (Quenstedt) has been recorded at Oakham Quarry, near Chipping Norton (Richardson, 1911, p. 228), and from near Lower Swell on the west side of the Vale of Moreton (F. B. A. Welch, in Richardson and Dines, 1929, p. 95). Both specimens have been kindly sent me on loan from the Geological Survey Museum. Although they leave a good deal to be desired I have little doubt that they are *Oppelia aspidoides* (Oppel), one of the commonest and most widespread Bathonian ammonites on the Continent. It was used as zonal index for the *Upper Bathonian* by Oppel, Neumayr, Haug and others, and is common to the Upper and Middle Bathonian of more recent classifications, but not the Lower. If this identification is correct there is a considerable disconformity between the Chipping Norton Limestone proper (Middle Bathonian) and the Hook Norton Limestone (Upper Bajocian).

Above the Chipping Norton Limestone follow the thin and variable Sharp's Hill Beds (= "Neaeran Beds"), mainly clays, which have been exhaustively described by Walford (1906) and Richardson (1911). Although these beds are 8ft. thick in the quarries at Charlbury and 7ft. at Buckleap Quarry, Cornbury Park, elsewhere they thin out to 2ft. or even disappear altogether. (See Table I.) They make a small showing of clayey soil in the immediate vicinity of the Charlbury quarries, but elsewhere it has been found impossible to map them.

The Stonesfield Slate Beds likewise cannot be mapped separately, their maximum thickness being about 5½ft. From the distribution of the old shafts and tip-heaps it appears that the true slate beds with *Trigonia impressa* are restricted to a very small area, immediately surrounding the village of Stonesfield, as remarked by Hull (1859, p. 18). The ellipse, hardly two miles long, shown on the map (Plate 3) by a heavy broken line, encloses all the signs of old workings.

The Taynton Stone, therefore, which is usually 20–22ft. thick, cannot in practice be mapped separately from the Chipping Norton Limestone, which it resembles lithologically. Both consist predominantly of more or less false-bedded white oolites, which weather flaggy, producing what are aptly called flatstones in Oxfordshire. Locally the upper part of the Taynton Stone is sandy and has been worked for inferior slates: as at Hillbarn Farm, and at Fulwell, just off the north corner of the map (Fulwell Slates: see Walford, 1906, p. 24). At the old limekiln quarry half a mile E.S.E. of Ranger's Lodge, Wychwood Forest, the Taynton Stone (seen to 9ft.) contains a bed of pure sand. Dressed setts were still being produced here on a small scale in April, 1945, but the stone nowhere seems to have the qualities that made it famous at Taynton, Burford, and Barrington.

Accordingly, within the area of the present map, it has been found practicable to map only as a single unit the beds from the top of the Clypeus Grit to the top of the Taynton Stone. These beds, together 40–50ft. thick, behave as a single limestone bed, characterised by weathering at the surface to oolitic flatstones, occasionally to non-oolitic sandy flags. Although forming with the Clypeus Grit the lower of the two limestone groups that build the Oxfordshire hills, this rises into the highest ground, above the 600ft. contour in the northern corner of the map. From there its surface falls rapidly towards Charlbury (for reasons to be examined later) and forms the platform that runs so conspicuously through the upper half of the gorge at a level of about 300–330ft. At Ashford Mill this platform coincides in level with the Hanborough river terrace, and at this point it retains three small outliers of gravel; but it is none the less a structural bench. Soon afterwards the bench sinks below alluvium level on the meander cusp near Westfield Farm.

TABLE I. THICKNESSES OF THE GREAT OOLITE SERIES AND CLYPEUS GRIT

Subdivisions	1 Charlbury	2 Wychwood Forest	3 Cornbury Park	4 Ramsden- Wilcote	5 Ashford Mill and Hanboro'	6 Combe	7 Maxima
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Combrash	...	...	...	...	...	...	...
Forest Marble	...	...	...	...	...	...	...
		4+		11 0 25 0	8 6 25 0	1+ 74	11 0 25 0
White Limestone	...	54 0		52 0	50 0		54 0
Hampen Marly Beds	...	20 0		26 6	21 0	22 0	26 6
Taynton Stone	...	14 0	20 (+?)	14 0	22 6	20 8	22 6
		29					
Stonesfield Slate Beds	...	(?) 1 3	— —	— —	— —	5 2	5 0
Sharps Hill Beds	...	8 1	7 0	2 6	6 6		8 0
Chipping Norton Lst.	...	23 6	23 0	28 0	15+	22 0	28 0
Clypeus Grit	...	c. 20 (+?)	35 0	20 (+?)	22 0	35 3	35 0
						Total	215 0

SOURCES FOR TABLE I

1. Charlbury : Quarries and well near Ditchley Road, Charlbury, and well at Charlbury Lodge, Ditchley Park (Walford, 1906, pp. 22, 23).
2. Wychwood Forest : Boring at Waterman's Lodge, 1934. Geol. Survey record, author's interpretation.
3. Cornbury Park : Buckleap Quarry (Walford, 1906, p. 22. Thickness of the Taynton Stone corrected by the author).
4. Ramsden-Wilcote : Boring at The Hayes, between the two villages, 1922. Geol. Survey record, author's interpretation.
5. Cuttings and quarries at Ashford Mill, Hanborough, Fawler, etc. (Arkell, 1931, pp. 610-615, and more recent measurements).
6. Combe : Boring on S. side of Notoaks Wood, between Combe and Stonesfield, 1934. Geol. Survey record, interpreted by L. Richardson (with minor amendment).

The lower half of the gorge is cut in the upper limestone group, comprising the White Limestone (50–54ft. thick). It is this subdivision that gives rise to the mural sides of the gorge where the incised meanders are developed. The Forest Marble, consisting mainly of clay with flaggy oolitic Kemble Beds irregularly developed below, and the thin Cornbrash (8–12ft.), are relatively insignificant in the landscape until they fall to near alluvium level in the last meanders. These subdivisions have been described before (Arkell, 1931 ; Douglas and Arkell, 1932). The hard surface of the White Limestone builds the tableland about Stonesfield. Although some of it coincides in level with the Combe river terrace, no gravels survive on it until the dip brings in the Forest Marble clay and Oxford Clay towards Combe. The Forest Marble clay accounts for the magnificence of the old oak trees in the southern part of Blenheim Park.

The upper and lower limestone groups are separated by a clay bank, where the Hampen Marly Beds (20–27ft.) crop out. To determine the distribution of this subdivision over a larger area was one of the first stratigraphical objects of the mapping. It has proved very persistent. The characteristic marls and clays crowded with *Ostrea hebridica* Forbes and large *Rhynchonella concinna* (Sowerby) have been traced on the fields on both sides of the valley from Whitehill Wood cutting, where they were first recognised (Arkell, 1931, p. 612), to the hills between Charlbury and Chipping Norton and the far side of Wychwood. Especially fossiliferous field-localities are in New Park, Ditchley (near Norman's Grove), S. and S.W. of Banburyhill Barn, and in old quarries around Cranehill Lodge, Cornbury Park. In the five wells and borings (Table I, p. 93) the thickness is nearly constant, but here and there the outcrop disappears owing to sagging down (cambering) of the White Limestone (see below).

The top of the Hampen Marley Beds is a spring line second only to the top of the Upper Lias. Springs gush out at the point where the marly beds first rise above alluvium level in the gorge, at the foot of Jacob's Hill, opposite the Water Bridge, Long Hanborough, and at numerous places along the outcrop. Two of the biggest springs are the Ruddy Well, at the north-eastern edge of the map, which was once the main supply for Stonesfield, and the Lady Well, at the south-western edge, which has deposited a tongue of white tufa nearly half a mile long and at least 8ft. thick in the valley below Bridewell Farm (Plate 3).

The Oxford Clay includes some Kellaways Sand at an old pit 300yds. east of Hanborough Folly Bridge, but elsewhere Kellaways Beds have not proved to be distinguishable. Valleys beginning at the base of this formation, as also those beginning at the base of the Forest Marble clay, sometimes start with a swallet or a system of

swallets, sometimes of large size and great depth. The principal ones are marked on the map (Plate 3).

III. STRUCTURE

Cambers. Pocock (1908, p. 107), writing of the Evenlode and Cherwell, stated "the two principal consequent rivers of the district have eroded their channels along downfolds of the strata, which not improbably correspond with the original depressions in the Chalk platform on which they took their rise." Spicer (1908, p. 341) thought that these synclines "appeared . . . to be no more than a slight down-turning of the straight edges of the strata above the river-valley, [which] illustrates the way in which superincumbent strata sag when support is locally removed by underground solution."

In respect of the Evenlode, at least, both authors were right. The present survey, carried out in the light of the work by Prof. Hollingworth and his colleagues on the Northamptonshire ironstone field (1944), has established the existence of the superficial gravity-sagging called cambering, on both sides of the valley from Fawler upwards, and at two horizons. To Spicer is due credit for an early recognition of such structures, although it is likely that mechanical washing-out of marl and clay, as long before suggested by Witchell (1867, p. 225) in the Cotswolds, was a more potent cause than solution. But as Figs. 1 and 2 show, when all allowance is made for cambering, there remains a large valleyward dip which must apparently be attributed to ordinary folding along N.W.-S.E. axes.

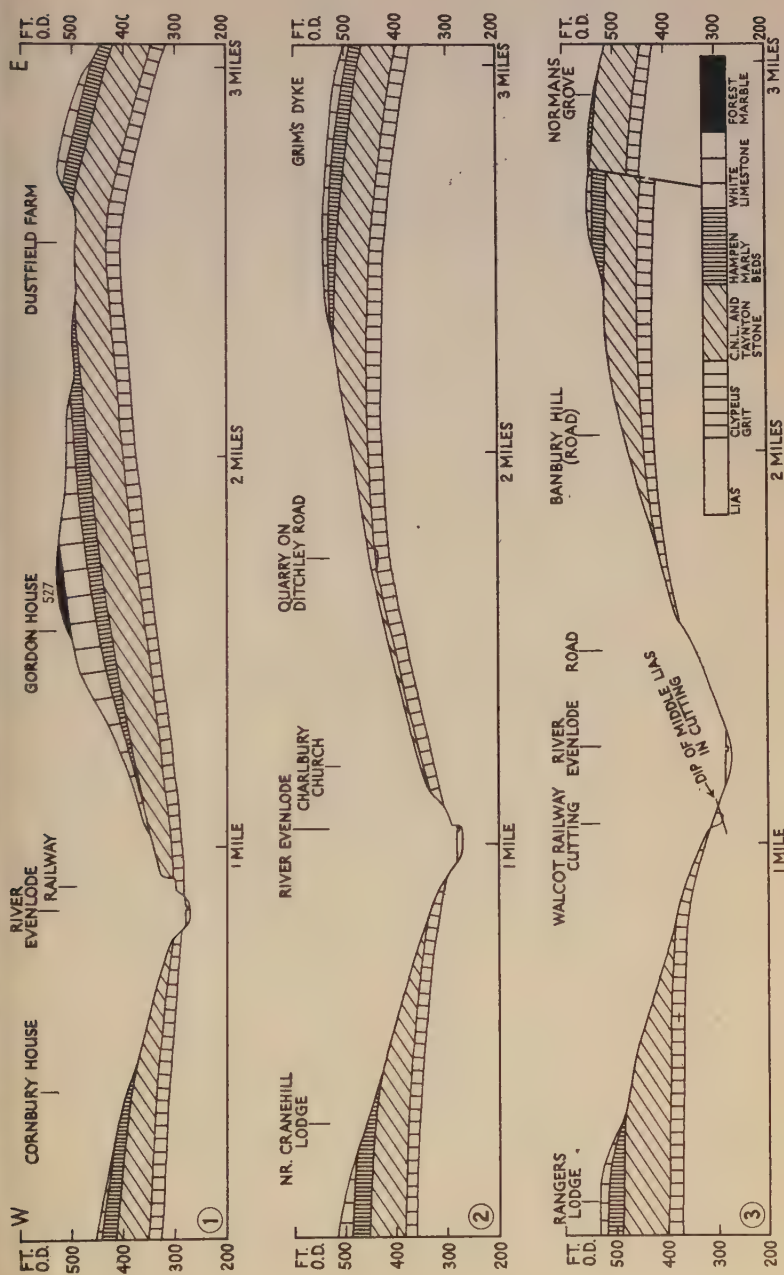
Each of the two horizons at which cambering is developed coincides with a spring line: the lower limestone group (Clypeus Grit, etc.) is cambered at the junction with the Upper Lias, and the upper limestone group (the White Limestone) at the junction with the Hampen Marly Beds. At the upper horizon the cambering is straightforward, but at the lower horizon it is difficult to disentangle the effects of cambering from those of folding.

Cambering of the White Limestone is most conspicuous on the east side of the valley, between Charlbury and Fawler, where the base of the formation repeatedly sags down in irregular flaps, obscuring, and in one or two places quite cutting out, the outcrop of the Hampen Marly Beds, which are normally 20-25ft. thick (see Table I, p. 93). Other good examples occur on the Ditchley road (Fig. 2) and near the old limekilns half a mile east of Ranger's Lodge, Wychwood (Fig. 3). The Hampen Marly Beds are partly cut out all round the Ranger's Lodge plateau, which is irregularly dome-shaped in consequence. The structures at these places are closely analogous with those figured by Witchell (1867, p. 224), where the Ragstones are cambered over the Oolite Marl.

Unmistakable cambering of the Clypeus Grit occurs on both sides of the funnel of the gorge above Charlbury : around Spelsbury and Taston on the east side and by Walcot and Shorthampton on the west (here south) side. The long flap of cambered Clypeus Grit at Shorthampton, in the west corner of the map, is a particularly good example and is important because its dip is almost due north, into the valley, but against the regional dip and almost at right-angles to the dip caused by the syncline referred to by Pocock. The fall here is about 30ft. At Walcot, too (Fig. 3), the northward and north-eastward fall of the lower limestone group towards the river cannot be due to the syncline, since the river and valley have not yet curved round into alignment with the syncline. The contrary dip of the Middle Lias in the railway-cutting, and the reported occurrence of Lower Lias at the same level between Walcot and Charlbury station (above, p. 89) suggest that the cambering here is compensated by bulging up of the Lias in the valley bottom (see below, p. 98).

From Charlbury south-eastwards, however, within the gorge, it cannot be cambering alone that brings the base of the lower limestone group suddenly down nearly to river level and keeps it horizontal for a mile and a half (see Figs. 1 and 2 and the horizontal section below the map, Plate 3). The fall in the top of the Clypeus Grit from the quarry on the Ditchley road to near the church exceeds 100ft. in half a mile, at right-angles to the regional dip. Again, half a mile to the south (Fig. 1), the top of the White Limestone is on the 500ft. contour near Gordon House, and the base rests on the Taynton Stone at the Fowler road near Baywell Cottage at an altitude of about 340ft. : a fall of 85ft. in the lower limestone group in half a mile, after deducting 50ft. for the thickness of the White Limestone and 25ft. for the camber-overlap of the Hampden Marly Beds just described. When drawing a section here, as in Fig. 1, it is found impossible to give the lower limestone group its full thickness of 80–90ft. without postulating a synclinal axis under the Fowler-Charlbury road, alongside and parallel to the alluvium ; but it is possible that the limestones are in fact reduced in thickness by solution at the valley edge as postulated by Spicer ; for the Clypeus Grit is said to be only 18–22ft. thick in the Fowler quarries, at the valley edge, whereas its thickness in several borings under the plateau on each side is 30–35ft. (see Table I). The reduction in the Upper Lias from the 31ft. proved in the Waterman's Lodge boring, Wychwood Forest, to 5–11ft. in the Fowler quarries (Bather, 1886) is likewise probably due to seepage-washing. Squeezing-out of clay at the valley edge has been postulated for some large cambers in Northamptonshire (Hollingworth, 1944), but so far no evidence for this has been found in the Oxford district, where Witchell's and Sharp's hypothesis is adequate to account for the structures.

Nevertheless, there remains a large riverwards fall in the Lower



Figs. 1-3.—Three sections across the map approximately West-East at half-mile intervals in the neighbourhood of Charlbury.

Oolites as a whole which cannot be accounted for by superficial movements, since the valley here is too narrow to allow for bulging up on a scale adequate to compensate for it and not enough of the Lias is missing (see Fig. 1). It appears that an anticline runs along the ridge separating the Evenlode and Glyme valleys, and that the dome at Dustfield Farm results from the interaction of this anticline with two small faults, though possibly the effect may be accentuated by cambering eastwards into the Glyme valley. The question cannot be finally settled until the Glyme and Cherwell valleys have been re-mapped. The existence of such an anticline would facilitate cambering; and the existence of such a dip, whatever its cause, would account for the intense spring-activity which has produced the long, narrow side-valleys at Charlbury and Taston. In some cases, at least, the siting of these spring-cut valleys has been determined by minor transverse structures. For instance, the Clypeus Grit is about 60ft. lower on the south side of the mouth of Clarke's Bottom, the first valley north of Charlbury, than on the north side. It is here that the large riverwards dip begins, and it appears likely that a small fault runs down the valley, although the effect dies out up the side-valley and is not perceptible on the opposite bank of the Evenlode. On the other hand much of the throw on opposite sides of the fault may be due to unequal cambering, the old fault-line having become a hinge between two unequally cambered flaps of limestone.¹

Ridge-and-hollow topography reminiscent of the Wytham Hills near Oxford (Arkell, 1947, pp. 145-8) is developed in the White Limestone only over a small area near the top of the slope west of Bevis Farm.

Valley Bulges. On the map (Plate 3) the numbers 1-9 in circles along the Evenlode valley indicate anomalies of structure which cannot be accounted for by ordinary tectonics. The details are described elsewhere (Arkell, 1947, pp. 150-1), and the localities are only briefly enumerated here for the sake of completeness.

1. Rock bluff on the left bank of the river west of Stonesfield Ford, showing a sequence from Middle Lias ironstone to Chipping Norton Limestone dipping 40° N.W. (see section below map, Plate 3).

2. Clypeus Grit "brought up by a sharp upfold or a fault" (Pocock, 1908, p. 10).

3. Clypeus Grit in road-cutting at Ashford Cottages, explained on the Survey maps by a fault running across the valley; but 6-inch mapping reveals no other sign of such a fault.

4. Vertical limestone at mouth of railway-cutting near Bridgefield Brake; Upper Lias clay on opposite bank of river raised above normal position.

¹ The word "flap" is used in this paper with its standard English meaning of a hanging or sagging piece of material hinged at one edge (e.g. flap of a pocket), without special tectonic implication.

5. Middle Lias ironstone in railway-cutting $\frac{1}{2}$ mile S.W. of Oaklands Farm dipping steeply N.E. into a fault breccia of Great Oolite, whereas 250yds. to the N.W. an old quarry shows the ironstone below the level of the alluvium.

6. Middle and Upper Lias and Clypeus Grit dipping 10° S.W. in the lane-cutting leading out of the railway-cutting into Topples Wood, figured by Hull (1859, p. 9), who measured the dip and remarked "the cause of this high angle is not apparent."

7. Lower and Middle Lias brought up by a sharp faulted anticline at Fawler, as noted by Bather (1886, p. 143).

8. Lower and Middle Lias (Margaritatus Zone with micaceous sandstone doggers as at Fawler in No. 6) exposed in the railway-cuttings at Charlbury and Walcot.

9. Nearly vertical thin Middle Lias ironstone in the right bank of the river, 40yds. below Catsham Bridge (Bather, 1886, p. 145).

All the above anomalies seem best accounted for as "valley bulges," like those described by Hollingworth, Taylor, and Kellaway (1944) in Northamptonshire. No bulges occur downstream from Westfield Farm, near which the top of the lower limestone group, 80-90ft. thick, sinks below alluvium and effectively holds down the Lias clays. The breaking of this cover rock in the valley near Stonesfield cannot date from a period earlier than the Wolvercote terrace; which brings the formation of these most southerly bulges down to a late period in the Pleistocene.

Orthodox Faults. It sometimes appears that small faults at right-angles to the valley have guided and blended their effects with differential cambering, perhaps determining the hinge-lines between unequally-cambered flaps of limestone and the siting of the principal springs and thence the spring-cut side-valleys. It is probable that such a fault determined the spreading of a valley bulge into the side-valley at Fawler.

Near the Evenlode-Glyme confluence, in the eastern corner of the map, there is a south-dipping monocline which accounts for the sharp fall of the Forest Marble from the north to the south bank of the Glyme (see section below map, Plate 3); this has nothing to do with "superficial" movements. Nor have the other small faults shown.

IV. GRAVELS AND BRICKEARTH

It is usual to classify terraced or river gravels according to their heights above modern river-level. But since the rate of fall of the Evenlode through the gorge (10ft. per mile; see Introduction, p. 87) is greater than is likely to have been the gradient of the ancestral river that deposited the Pleistocene gravels before the gorge existed, it is useless to measure heights of early terraces above the Evenlode except near the mouth.

It is important, for this reason, to distinguish between gravel terraces that ante-date the gorge and those that post-date the gorge. The latter pass through it and are graded parallel to the modern alluvium ; the former can be correlated only by constructing a gradient diagram on to which are projected the gradients of the same terraces farther downstream, in the Thames valley (Plate 2). Some terraces may be intermediate, dating from pauses during the cutting of the gorge ; one such terrace is represented by patches of gravel about 50ft. above the river near the mouth. For all terraces within the present area, therefore, stage-names based on places are used, rather than heights, or such designations as "first," "fourth," "flood-plain terrace," etc. Heights of gravel terraces or patches throughout this paper are surface heights. River-level is assumed to be alluvium level adjacent to the rivers Evenlode and Thames, since this remains constant while the water-level fluctuates seasonally and according to the weather.

Another important distinction is between limestone or oolite gravels of local origin, such as those composing the Hanborough and all lower terraces, and quartzose or erratic gravels, such as exclusively compose all higher terraces and gravel patches in the Oxford area.

NORTHERN DRIFT PLATEAU GRAVELS, NOT OBVIOUSLY TERRACED

Whatever the ultimate origin of the erratic pebbles of which these gravels are composed (see Sandford, 1929), they entered the Oxford area from the north, by way of the Moreton Gap, and may, therefore, most appropriately be called by Hull's name, Northern Drift. The continued discovery of new tourmaline- and cassiterite-bearing rocks and others of south-westerly origin in the Bunter pebble beds of the Midlands (Wills, 1945, p. 24) suggests that all the erratics of the Oxford district not found in the Great Welsh or Main Eastern glacial drifts of the Midlands (Wills, 1938) will eventually be traced back to the Midland Trias.

The untterraced patches of Northern Drift in and near the present area usually cap the hills, from 649ft. O.D. at Waterman's Lodge, Wychwood Forest (Tomlinson, 1929, p. 167) down to the level of the highest true terrace at just under 400ft. O.D. (Combe terrace, see below). Sometimes, however, the gravel runs down the hillsides in greater force than seems likely to be accounted for by surface-movement : for instance, in the patch at Hunt's Copse, north of Wilcote, on the side of a hill, sections showed Northern Drift gravel 3ft. deep, unbottomed.

The patch of Northern Drift marked (Plate 3) on top of the hill above Gordon House, one mile E. of Charlbury church (summit level 527ft. O.D.) coincides in height with the top of Cumnor Hurst

(520ft. O.D.), but it is only a scatter of quartzose pebbles irregularly studding an outlier of Forest Marble clay. The patch at Burleigh Lodge, in the extreme eastern corner of the map, lies in a valley and may be all downwash.

The most likely hypothesis yet propounded to account for the Northern Drift is that due to James Geikie (1877, p. 365), namely that the drift was brought by an ice-sheet or ice-lobe which penetrated south down the pre-glacial ancestors of the Moreton Gap and Evenlode valley from the main *mer de glace* in the Midland plain.

TERRACED NORTHERN DRIFT GRAVELS

The highest spreads of unequivocally terraced gravel adjoining the Evenlode are (1) the Combe terrace, on the north side of the valley, at 380–395ft. O.D. or 160–175ft. above the river near the mouth of the gorge; and (2) the Freeland terrace, on the south side of the valley, at 350–365ft. O.D. or 130–145ft. above the river near the mouth of the gorge. Both sheets consist exclusively of Northern Drift gravel.

The Combe terrace is now left by erosion on the top of a watershed ridge between the Evenlode and the Glyme, but its terrace form and parallelism with the Evenlode valley are unmistakable; and it is continued just outside the map by a further outlier on Bladon Heath, in line with the other patches. This terrace is remarkable for the abundance of large erratics, 6–8in. long, mainly quartzite, vein quartz, and Millstone Grit. They are more abundant than on the fields on higher patches of the Drift, but similar large blocks have been noted here and there at higher elevations, for instance at Wilcote.

From the lithology and the levels it is probable that the Combe terrace, as well as at least some of the lower untterraced patches such as that at Perrotshill, correlates with the large mass of coarse Northern Drift on the Lias about Bruern Wood and Fifield Heath, higher up the valley (see Plate 1), which is interpreted as ground-moraine by Tomlinson (1929, p. 177) and as boulder clay by Dines on the Witney sheet of the Geological Survey map (1938). At Bruern there can be no doubt that the drift occupies part of the floor of the pre-Glacial Evenlode valley, and the Combe terrace, therefore, may be "sorted by water on what was then the bottom of the valley," as suggested by Pocock for the Freeland terrace (1908, p. 97). It is thus conceivable that the appearances of overthrusting formerly observed in Combe brickyard (Sandford, 1924, p. 122) may be due to ice action; but the brickyard is close to the edge of the hill and solifluxion is a possible alternative hypothesis. (Cf. Peartree Hill, near Oxford, described by Bell, 1904, p. 128.)

The Freeland terrace, on the opposite side of the valley and about 30ft. lower, has a still more unmistakable terrace form, and

is preserved for a width of a mile at its widest and a continuous length of two miles. Pocock (1908, p. 97) remarked that this spread is rudely bedded and added that it "is inseparable from the rest of the deposit and is most probably of the same epoch," but this is disproved by more careful mapping. The Freeland terrace is separate from both the higher Perrotshill patch and the Hanborough limestone-gravel terrace, from each of which it is bounded by a clay step. Here and there the clay steps carry surface trails of pebbles spread by ancient solifluxion, hill-washing, or surface-creep, but the auger can be inserted everywhere and the true boundaries of the terraces are marked by seepages and spring-lines. Doubtless the confusion of such marginal surface-spreads on Oxford Clay with the true drift deposits is responsible for the statements that the matrix of the Northern Drift is "a tenacious clay." Where undisturbed, the matrix is generally fine gravel, sand, or loam (see also Richardson, 1935, p. 406), though sometimes the terrace is covered by a heavy soil probably of extraneous origin.

On the whole the gravel of the Freeland terrace is finer-grained than that of the Combe terrace and the large erratics are absent or much rarer. An exception is conspicuous along the outer, western, edge, where the gravel abuts against higher ground (Oxford Clay). Along this edge, west of Cuckoo Lane and within the confines of Eynsham Hall Park, south of the sawmills, there is a fringe of very coarse gravel crowded with large erratics and rising to 12ft. above the general surface of the terrace. This marginal deposit is probably somewhat older than the rest of the terrace. It appears as if the river after abandoning the Combe terrace swung over to the south side of the valley while still carrying the large erratics and deposited this marginal bank before the prolonged halt at the Freeland level.

A little farther south, near the south-western edge of the map, the terrace gravel becomes finer and sandier than elsewhere, and at the same time the margin swings round westward by Eynsham Hall Home Farm. This appears to have been the point of junction with the proto-Thames of the Freeland stage.

The gradient-diagram shows that it was at or before the Freeland stage that the Windrush last flowed into the Evenlode by way of the Bridewell Farm-Hollycourt Farm valley (Pocock, 1908, p. 93). Less than a mile beyond the edge of the map the valley is blocked by a deposit of Northern Drift at a minimum height of 355ft. O.D. (see Witney sheet). The amphitheatre-like ridge of high Oxford Clay at North Leigh and Perrotshill represents the last meander cliff of the old river, at the foot of which relics of its gravels still cling to the spurs. The gravel is all Northern Drift (7ft. thick in North Leigh churchyard) except in the last patch towards Hollycourt Farm, which is some 10ft. lower than the others and consists largely of limestone gravel. This patch cannot be either Windrush

or Evenlode gravel and probably represents a later small tributary of the Hanborough stage, draining the lower end of the abandoned Windrush valley and the surrounding hills.

The gravel of the Combe and Freeland terraces is much thinner than that of the oolitic Hanborough and Summertown terraces. The Combe terrace has been worked in small pits (now ploughed) half a mile N.W. of Combe Church, and the Freeland terrace in a shallow "sand-pit" at the Demesnes, east of the East End road and north of the brick-pit: a marked contrast with the 12 large pits on the adjacent Hanborough terrace. It may be doubted whether the gravel on the Combe and Freeland terraces anywhere exceeds 5ft. in thickness.

TERRACED LIMESTONE GRAVELS

The **Hanborough terrace**, which is continued by a large outlier at Purwell Farm, beyond the south-eastern edge of the map, like the Freeland terrace, represents a great delta of the Evenlode. The preserved parts are three miles long by up to a mile wide, and the gravel is commonly 15ft. thick. It is the last big gravel deposit to precede the cutting of the gorge. Probably the choking of the mouth of the river by this delta led to the formation of the meanders, which later became incised and gave the lower part of the gorge its peculiar character.

Although the drop from the Freeland terrace is only about 30ft., there is a fundamental change in the composition of the gravel. The Hanborough gravel consists overwhelmingly of white or cream limestone pebbles, although erratic pebbles are still plentiful, perhaps derived from earlier terraces. Three causes of this change in lithology are possible: (1) Decalcification of all earlier gravels. (2) The intervention of a phase of deep downcutting, during which the Northern Drift was cleared out and the Oolites laid bare, followed by aggradation to the Hanborough level; (3) Sterilisation of the oolitic subsoil by lack of precipitation or deep freezing, or both, during the deposition of the Combe and Freeland terraces, while erratic material was supplied from an ice-front in the Vale of Moreton. On the third hypothesis the Combe and Freeland terraces would have originated during a glacial period, while the Hanborough terrace would be interglacial, its materials derived from solifluxion at the end of the preceding glacial period and contemporary erosion of the surrounding hills. The least satisfactory explanation is the first, which postulates an extraordinarily potent process of decalcification during the interval between the Freeland and Hanborough stages (only 30ft. apart); a process never repeated, since the Hanborough gravels are unaffected by it, and a process with selective action on gravels, since the limestone rocks of which the country is mainly composed were not proportionately affected. The third hypothesis, without invoking

decalcification, accounts for the difference in composition and thickness of the gravels and for the absence of fossil bones in the Combe and Freeland terraces and the presence of fossil mammalia of warm-climate facies in the Hanborough terrace.

The composition, fauna, etc., have been fully described by Sandford (1924, 1926). The implications of these Thames and Evenlode terraces, however, with their successive faunas, differing from the higher terrace to the lower, yet both of warm-climate facies, can hardly have been adequately considered either by those who maintain that all aggradation terraces correlate with glacial epochs or by those who entertain the idea that the terraces result from "deep valley fill followed by progressive erosion in a single uninterrupted cycle" (cf. *Geol. Mag.*, 1945, vol. lxxxii, pp. 10, 16).

Picturesque features revealed by the present survey are the marginal deposits of the terrace banked against the clay step below the Freeland terrace, and partially severed from the main outcrop by stream-erosion. The long finger-like extension of the gravel south of Church Hanborough represents a filled channel in the delta (not necessarily the only one, since others may have been destroyed during the swing-back of the river towards Combe), as appears from the sagging of the base of the gravel below the 300ft. contour. From the S.E. side of the Hanborough finger the channel crossed to the S.W. side of the Purwell Farm outlier, where similar features are repeated and the gravel is banked against Oxford Clay forming higher ground to the east.

At Hanborough this terrace is high above the gorge and obviously antedates it, but two miles upstream, just above the region of meanders, three small patches of gravel at the same height near Ashford Mill serve to show that there the river of the Hanborough stage flowed well within the broader valley enclosed by the upper limestone group (the White Limestone).

These gravel patches, unusual because on limestone, link the main gravel deposit on the Oxford Clay at Hanborough with equivalent deposits on Lias Clay in the funnel above the gorge, between Charlbury, Spelsbury, and Chadlington. This relic of the Hanborough terrace has been dissected by streams from the higher ground behind into five outliers, all of which can be seen to be banked against the clay slope of the valley and truncated in front by erosion. There are six principal pits (marked on the map, Plate 3). The best at present, 350yds. N.W. of Dean Grove, Spelsbury, shows 12ft. of limestone gravel, closely resembling that at Hanborough except for a higher proportion of *Clypeus* Grit fragments (as might be expected), overlain by 1-2ft. of clayey soil. Another pit near Coldron Mill, 200yds. east of Dean Grove, shows 15ft. of gravel and brown sand, the sand predominating. A peculiar feature of these terrace outliers is that the patch farthest upstream is the lowest in elevation, a fact not satisfactorily accounted

for by subsequent erosion, but probably due to the part of the terrace nearer Spelsbury being farther from the centre of the river of Hanborough times, where the bottom would not have been scoured so deep and more gravel from the hills behind would have been deposited. Clypeus Grit fragments form a high proportion of the gravel in these patches and much of the material is but little rolled although it passes laterally on the same level into normal river gravel. The heights obtained for the tops of two of the highest patches (353ft. and about 354ft.) fall exactly into line with the gradient diagram of the Hanborough terrace although this level is only about 70ft. above the adjacent Evenlode alluvium, as compared with 90-100ft. at Hanborough (Plate 2).

Wolvercote terrace. This stage is represented only by a few very small gravel patches. Two on the right bank of the Evenlode near Hanborough Station show only quartzose gravel on the fields, but two on the left bank, in Blenheim Park, and S.E. of Folly Bridge, Hanborough, consist of limestone gravel and have both been worked in pits. The latter patch (or patches) occupies an unexpected position in the apex of what must have been a hairpin meander of the period. Another patch on a meander spur below Whitehill Wood is cut through by the railway-cutting, which displays some oolite gravel banked against Hampen Marly Beds and overlain by stony loam with quartzites and flints. Flints are much commoner and fresher in this terrace than in the Hanborough gravels. Evidently in the Evenlode valley, as on the Thames, the Wolvercote stage represents a halt of comparatively brief duration, but in the Cherwell valley the terrace is more important.

Summertown terrace. By the time this terrace was formed the gorge had reached essentially its present depth and shape, although some of the big incised meanders have since changed their positions, owing to their narrows having become choked with limestone gravel during the aggradation that produced the terrace. There are three of these abandoned incised meanders, all near the lower end of the gorge. The first, at Combe Sawmill, on the left bank, retains little of the meander form and is but an imperfect example, but a considerable tract of gravel remains, rising to 15ft. above the alluvium close to the present river bank, and to about 20ft. behind. From here the river of the Summer-town stage swung south into the splendid abandoned meander below Long Hanborough village described by A. M. Davies (1923). Only the upstream end retains the gravel filling, and this has been opened up at Wallace's Quarry, described below. The top of the bedded gravel is 25ft. above the adjacent river bank and is overlain by thick stony brickearth and head which would completely mask the gravel but for the artificial exposure.

The last abandoned meander is less spectacular because it is at the very mouth of the gorge, where all the hard rocks but the

Forest Marble and Cornbrash have sunk below the level of the alluvium, but it is singularly perfect. The detached meander-core at Hanborough Mill is of Cornbrash, and almost the whole channel, except at the downstream end, is still full of gravel to the brim. The gravel has been exploited in some half a dozen pits.

Within the gorge the downstream side (or "slip-off slope") of most of the meander cusps is mantled in gravel of this stage, often more or less masked by later brickearth. Above the gorge there are remnants of the terrace gravel for considerable distances, mainly on the left bank (as shown by Miss Tomlinson, 1929, pl. vi). There are exposures in river cliffs 100yds. below Catsham Bridge and again below Dean Grove, Spelsbury, and the usual height of 25ft. above alluvium is maintained.

Northmoor terrace (see Arkell, 1943, Table I). This Thames terrace (5–10ft. above alluvium) enters the mouth of the Evenlode valley opposite Eynsham Mills, and is represented within the gorge by occasional fringes of low-level gravel along the alluvium edge, not separated on the map. The biggest outcrop fills the bay east of the Water Bridge, Long Hanborough. Probably the gravels of this stage are mainly under the alluvium both here and in the Vale of Moreton (cf. Tomlinson, 1929, p. 173). Above Charlbury there are low banks of gravel and sand above the alluvium level, but there is nothing in their form to warrant separating them from the Summertown stage, of which they commonly seem to be degraded relics.

Brickearth. A deposit of brickearth about half a mile long is banked against the north-east-facing side of the last abandoned meander, adjoining the south-eastern edge of the map. It is within the meander and apparently post-dates the filling and abandonment of the meander. Smaller and less definite spreads of brickearth, often more or less mingled with small pebbles, occur at intervals throughout the gorge, especially on meander cusps over Summertown gravels or near the alluvium edge. It is just possible that these represent a sandy facies of the upper part of the gravels, such as is seen in one of Smith's pits, Cassington.

Wallace's Quarry, Long Hanborough (Fig. 4) shows a section of up to 20ft. of dirty, stony brown brickearth interfingering towards the Pleistocene river cliff with angular limestone head, and resting on the top of the Summertown terrace gravel at 25ft. above alluvium. While the limestone is obviously due to disintegration (albeit on an extraordinary scale) of the steep bluff behind, the sand, like that in the Cheltenham Sands, cannot be of strictly local origin. There is no corresponding sand deposit on the hill above to provide a source, nor elsewhere in the neighbourhood, except as the winnowings of earlier gravels. It was probably brought to its present position by wind, then re-worked by solifluxion.

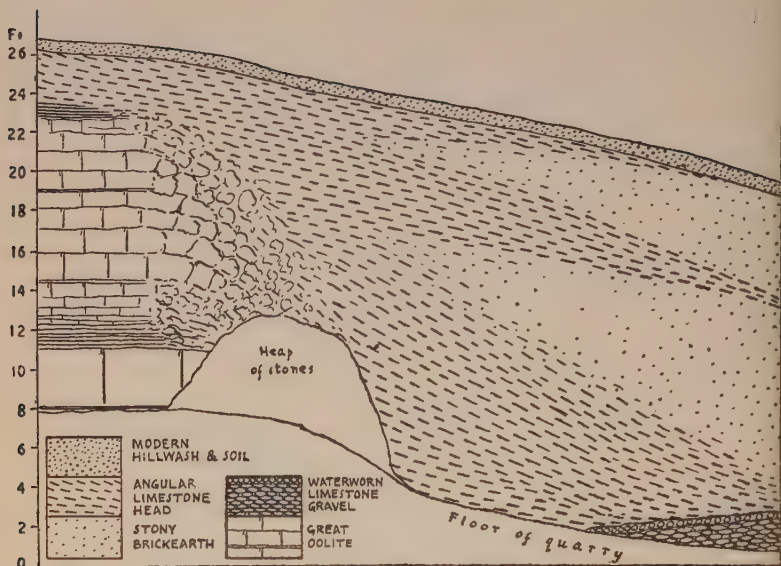


FIG. 4.—SECTION OF HEAD MERGING INTO THE PLEISTOCENE RIVER CLIFF, WALLACE'S QUARRY, LONG HANBOROUGH.

The waterworn gravel has an indurated top which has been subsequently tilted into the hill (by slipping ?) ; and it has been shown closer to the old cliff than where actually seen, to bring it into the diagram.

V. THE AGE AND ORIGIN OF THE GORGE

The lower Evenlode—upper Thames succession

The following stratigraphical and climatic succession in the Pleistocene deposits of the Oxford district was established by Pocock (1908) and Sandford (1924, 1926) (the oldest being No. 1) :

1. Northern Drift plateau gravels : erratics imply glaciation.
2. Combe and Freeland Northern Drift terraces : now separated.]
3. Hanborough (100 ft.) terrace : warm-climate fauna [implements :— a single unrolled Abbevillian hand-axe (Arkell, 1947a)].
4. Wolvercote (50ft.) terrace : no fauna ; rolled Early Acheulian implements.
5. Summertown terrace, lowest gravel : cold climate (fauna).
6. Summertown (25ft.) terrace, upper gravel, and Wolvercote Channel basal gravel : warm-climate fauna ; Middle and "Later" Acheulian implements (Arkell, 1946 ; 1947, pp. 218-21).
7. Northmoor terrace (5-10ft.) : no reliable fauna or implements.
8. Trail ; brickearth ; silt in Wolvercote Channel : cold-climate fauna and flora ; a few flakes of " Mousterian " type in the silt of the Wolvercote Channel.

The present survey of the Evenlode gorge and its surroundings has revealed nothing additional to this succession (except that No. 2 has been separated), and nothing inconsistent with it.

The Moreton Gap succession

The following succession was established by Miss Tomlinson (1929) on the upper Evenlode and in the Moreton Gap, and I have satisfied myself of its essential correctness subject to the reservations stated in square brackets. (The oldest is No. 1):

1. Northern Drift (Plateau Drift).
2. [Lower] Campden Tunnel Drift [Stretton Sands]. [Only the lower part at Campden Tunnel, the pink sands formerly worked at a depth of 20-40ft. for building-sand, and equivalent to the building-sands of Stretton-on-Fosse, which are overlain by Paxford Gravel, are proved to be of this age. The fresh upper drift exposed in the gravel pit at Campden Tunnel, mainly composed of subangular Lias limestone with many Gryphaeas and belemnites, may be the local equivalent of Nos. 3 or 4.]
3. Paxford Gravels (Ditchford Gravels): waterworn Jurassic limestone gravels forming a terrace on the north side of the present Stour-Evenlode watershed. [Seen resting on No. 2 at Parsons' Stretton-on-Fosse sand pit, opened 1943.]
4. Moreton Drift (Eastern Drift): boulder clay and glacial sands and gravels abounding in fresh flint and chalk. [Seen resting on No. 3 at Stretton sand pit and Great Wolford pit.]
5. "Bledington terrace": waterworn limestone gravels 20-30ft. above the river in the southern part of the Vale of Moreton. [The gradient-diagram, Plate 2, suggests that this terrace is the continuation of No. 3, and I am satisfied that it is overlain at Bledington by sand, loam, and abundant fresh flints belonging to No. 4. See below, p. 109.] [A palaeolithic hand-axe recorded from gravel at Kingham (Fowler, 1913) presumably came from this terrace.]
6. Valley gravels close to or below alluvium.

In addition, Dr. Tomlinson (1929, pp. 174-5) drew attention to an occurrence of limestone gravel with surface-height 400-410ft. O.D. (90-100ft. above the Evenlode), overlain valleywards by reddish sand, at Upper Milton, near Milton-under-Wychwood. A new pit at Upper Milton opened in 1939 exposes 16ft. of this limestone gravel and shows it to be not a river terrace, but an angular solifluxion or torrent fan, with deposition dip up to 12° towards the valley. It occupies the mouth of a coombe or side-valley leading from the Oolite hills and is a fan-gravel comparable with those since described in numerous similar situations along the Cotswold escarpment (Tomlinson, 1941).¹ With which terrace it connects is uncertain owing to advanced dissection, but although the gravels into which it runs down are adjacent to the alluvium and, therefore, at first sight appear to correlate with stage No. 6 of Dr. Tomlinson's succession (above), it is more likely that they belong to a deep channel of stage No. 5 (=3) due to the narrows at Shipton. (See Plate 1.)

Correlation between the Moreton Gap and Upper Thames basin

Miss Tomlinson (1929, pp. 174, 187, pl. vi) stated that a line drawn through the surface of the Moreton Drift when continued down-stream coincides with the surface of the Spelsbury terrace

¹ Dr. Tomlinson and the writer have since visited the pit together and agree this description.

above Charlbury, which Sandford (1924, 1926) had correlated with the Wolvercote terrace at Oxford. On these grounds both Tomlinson (1929) and Sandford (1932, p. 7) correlated the Moreton Drift with the Wolvercote terrace of Oxford.

When the present mapping showed, however, that the Spelsbury terrace was a continuation of the Hanborough terrace, which contains a warm-climate fauna, it became clear that the Spelsbury terrace, which in any case is entirely different lithologically from any Moreton Drift and contains hardly any flints, could not be correlated with the Moreton Drift. I therefore suggested to Miss Tomlinson that her gradient diagram is equally consistent with the idea that the Combe and/or Freeland terraces represent the outwash of the Moreton Drift, and that a connecting link might be a patch of gravel indicated in her diagram at Chesnut Close, between Ascot and Milton. In a previous paper I adopted this correlation as the best working hypothesis (Arkell, 1943, p. 151 and Table I).

Further survey of the lower Evenlode, however, has brought home to me serious difficulties. The correlation implies that the Paxford Gravels in the Moreton Gap are older than the Freeland terrace; for the Moreton Drift boulder clay and glacial sands and gravel are seen actually resting upon the Paxford Gravels in a big pit at Great Wolford, east of Upper Lemington (Tomlinson, 1929, p. 163; Richardson and Dines, 1929, p. 127) and in Stretton sandpit. I am satisfied that no bedded and waterworn limestone gravels comparable with the Paxford Gravels that could possibly be older than the Freeland terrace occur in the present area, nor are any likely to have escaped notice elsewhere in the upper Thames basin. From their height above O.D. and their geographical position, on the other hand, the Paxford Gravels appear to be a continuation of the Hanborough-Spelsbury terrace, since separated from the Evenlode by encroachment of the rapidly-eroding Knee Brook draining to the Avon. (See gradient-diagram, Plate 2.) Lithologically the gravels are closely comparable, even to the capping of "chocolate-coloured" or "stiff red" clay described in the Moreton Gap (Tomlinson, 1929, pp. 169, 184) and in one of the pits in the Spelsbury terrace (Sandford, 1924, p. 129). This correlation, moreover, brings into line the archaic *Elephas antiquus* tooth obtained from Jurassic (Snitterfield) gravels underlying an eastern boulder clay near Stratford-on-Avon, compared by Sandford with the teeth from the Hanborough terrace (Tomlinson, 1935, p. 456); though too much weight is not attached to this evidence in view of the range of most of the Pleistocene mammalia through two or more interglacial periods.

If the Paxford Gravels correlate with the Hanborough terrace, there is still the earlier part of the Campden Drift (Stretton sands) to equate with the Freeland terrace (Table II). Lithologically this

makes a much better correlation, for the Lower Campden Drift is characterised by Welsh rocks and comparatively few flints, and therefore appears to be a more likely source for the Freeland erratics than the later drift full of fresh flint in the floor of the Vale of Moreton. A link is provided by the terraced, current-bedded, pebbly sands at Rynchill Farm, near Kingham (Plate 1). The height of these (up to 411 ft.) is great enough to link with the Combe terrace, but lithological agreement with the Freeland terrace is closer: the excess height upstream of Bruern may be due to blocking of the centre and west side of the valley by boulder clay. Moreover, the paucity of flint in the Hanborough-Spelsbury terrace (as noted at Spelsbury by Miss Tomlinson, 1929, p. 174) is more consistent with the idea that the Moreton Drift, a few miles higher up the valley, is younger, rather than older, in which case there should have been a plentiful supply of derived flints. Flint is equally scarce in the gravel of the "Bledington terrace" in the pit S.E. of Bledington Church, and the gravel is "piped" like the Hanborough terrace at Hanborough, and flint is more abundant in the loamy filling of the pipes, and on the surface of the ground above the gravel. These pipes do not occur on the Summertown terrace about Oxford although good exposures are numerous. This fact and the gradient diagram (Plate 2) suggest that the Bledington terrace also belongs with the Hanborough-Paxford stage.

Fresh flint first appears in relative abundance in the lower Evenlode valley and upper Thames basin in the gravels of the Wolvercote terrace, so far as may be seen in the meagre exposures at Whitehill Wood railway-cutting,¹ in the Blenheim Park gravel pits,² and at the old brick-pit at Peartree Hill.³ But it does not follow from this that the Wolvercote terrace is contemporaneous with the Moreton Drift and represents outwash from the eastern ice. There are few occurrences and still fewer exposures of the Wolvercote terrace, but such as there are show a proportion of flints and other erratics insufficient for what might have been expected of an outwash gravel from the intensely flinty Moreton Drift. The Wolvercote terrace gravel, where fully represented, is predominantly composed of waterworn limestone fragments like that of the Hanborough, Summertown and Northmoor aggradation terraces, and it appears to be a subordinate member of the same series. From these facts I have concluded (Arkell, 1946) that the Moreton Drift is older than the Wolvercote terrace and a product of the Ca glacier,⁴ and that it did not leave any considerable outwash gravel in the Oxford district. Apparently the glaciation is

¹ Marginal fragment: the flints occur in brown loam; little oolite gravel exposed.

² Mainly oolite gravel, but face sloped; flints abundant in debris.

³ Residual patch consisting wholly of quartzose gravel and loam with abundant flint.

⁴ For explanation of symbols used to avoid confusing and question-begging reference to East Anglian and Alpine timescales, see Arkell, 1943, p. 150 and Table I.

TABLE 2. CORRELATION BETWEEN THE VALE OF MORETON AND UPPER THAMES

¹ ENGLISH GLACIATIONS	² MIDLANDS (WILLS)	³ MORETON GAP	⁴ EVENLODE GORGE EVENTS	⁵ OXFORD SUCCESSION
	Alluvium	Alluvium	Alluvium Spring valleys cut	Alluvium
Cy	Little Welsh (Cy) and	Valley gravels and Dorn fan-gravel	Brickearth Aggradation in valley floor	Brickearth Buried Channel
Co	Main Irish Sea (Co) glaciations	Erosion	Erosion : some meanders abandoned	Northmoor terrace Erosion 20ft.
	Kidderminster terrace (Avon terraces Nos. 3 and 4)	Valley gravels ?	Meanders choked with oolite gravel	Summertown terrace
		Erosion	Erosion ; meanders deepened	Erosion 30ft.
		?	Aggradation and solifluxion	Wolvercote terrace
Ca	Main Eastern 2, 3 Great Welsh 2, 3 glaciations	Moreton Drift	Erosion : meanders incised by meltwaters	Erosion, 50ft.
	Jurassic Gravels of Snitterfield, etc.	Paxford Gravel and Bledington terrace	Meanders initiated in valley choked with oolite gravel	Hanborough terrace
	Great Welsh 1 and	Erosion	Erosion	Erosion 30ft.
Be	Main Eastern 1 glaciations	Lower Campden Drift (Stretton Sands)	Thin erratic gravel terrace	Freeland terrace
		Bruern Northern Drift	Erosion Thin erratic gravel terrace	Erosion 30ft. Combe terrace

Entry of Northern Drift ice-lobe

unrepresented downstream, unless by the brown pebbly loam on top of, and piped down into, the Hanborough terrace, and by erosion.

The age and origin of the gorge

If the above correlation is correct (Table II), the Evenlode gorge as we know it began to be cut during the melting of the Ca glacier. During the preceding interglacial the valley through the upper limestone block had become choked with limestone gravel (Hanborough terrace) and the river picked its way over the gravel in the valley and over the delta in a series of big meanders. Then with the onset of the Ca glaciation an ice-lobe for the second time entered the Vale of Moreton from the north and the supply of local rock-waste was shut off. Soon afterwards, perhaps in consequence of lowered sea level, but possibly only because of reduced load, the Thames was rejuvenated and quickly lowered its bed, which hereabouts was on soft Oxford Clay. The Evenlode, in response to the lowering of local base-level, deepened and incised its meanders, but its limestone bed proved too hard to allow it to keep pace with the upper Thames, and there resulted the steepening of the gradient through the gorge which persists to this day.

During the Ca-Co interglacial not only was the gorge eroded down at least to present river-level, but at times the choking with local limestone gravel was repeated, first on a minor scale with the Wolvercote terrace, then more effectively with the Summertown terrace, with its *Hippopotamus* and *Corbicula* beds. This time on the Evenlode (and other Cotswold tributaries) it was not an ordinary river valley into which the great slough of fragmented limestone descended, but a tortuous gorge. When rejuvenation set in again with the last glaciation (Co-Cy) the river in flood burst across the necks of three meanders in its search for an easier outlet to the Thames. Incised meanders choked with gravel were abandoned also on the Windrush, Glyme, and Cherwell at this time.

The cold winds of the last glaciations winnowed the exposed gravels of the preceding stages and drove sand on to the abandoned gravel banks and against the retaining cliffs and spurs of the gorge. At the same time the upstream side of each meander spur was trimmed by the current.

Since then the Evenlode has aggraded its bed with alluvium and developed the new meanders on a smaller scale, within the old, which have made the river a classic example of a "misfit."

Age and origin of the side-valleys

It is a remarkable fact, as noted by Spicer (1908), that the tributary dry (or almost dry) valleys or coombes which join the Evenlode and other similar rivers at right-angles are completely free from terraces or gravels. If these had been the channels by which the bulk of the Oolite gravels had been fed into the main

river valley it might have been expected that deposits would be left in them here and there, or even that some of the valleys, especially in the dry upper reaches, would remain blocked with detritus ; but no such deposits or blocked valleys exist.

The explanation seems to be that the present system of side-valleys is due almost entirely to spring-head erosion, often combined with underground swallet-action, and is of much more recent origin than the main valley. In order to illustrate the connection between the side-valleys and the springs and swallets, the most important examples of both are shown on the map. More perfect valleys of this kind could hardly be found in any area, and they merit a study to themselves. Many of the coombes continue far beyond the existing springs and so must have been cut at a time of higher water-table.

[Note added in proof : The Witney memoir appeared while this paper was in the press. It contains a valuable account by L. Richardson of the origin of the dry valleys in the country immediately to the west of our area, and the above brief remarks entirely bear out Richardson's conclusions.]

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DISCUSSION

Dr. A. E. TRUEMAN was pleased to find that the Author had collected more precise information about the minor structures in the area, and especially that he had demonstrated the existence both of "camber" and of gentle folding. He agreed that camber was widely distributed in many parts of the Cotswolds.

Recently a number of his students at Glasgow had attempted to produce stratum contour maps of deeply dissected areas in the Cotswolds, in Chalk country of low dip, and in south-east Devon, using mapped outcrops and boring records. In almost every area the stratum contours produced appeared to show that the drainage followed gentle synclines, although from the complex pattern it was apparent that the structures could not in detail be due to folding.

This raised in his mind the question of numerous records which have been published concerning the thicknesses of certain Jurassic rocks in particular. Some of these represent measurements made in quarries or trenches on valley sides. He wondered whether Dr. Arkell would agree that the value of many of these must be suspect. It was perhaps significant that a close relationship had been shown to exist between minor thickness changes in these rocks and the positions of transverse drainage lines; it appeared that these frequently followed lines where certain strata were diminished in thickness, whereas the areas of thicker deposits formed a "bulge" on the outcrop. Was it possible that these views were in some cases based on erroneous interpretations of the valley sections?

Mr. C. E. N. BROMEHEAD and Dr. K. P. OAKLEY also spoke.

The AUTHOR in reply to Dr. Trueman said that he had become convinced in the field that many Mesozoic outcrops required re-examination in the light of what had been revealed by the ironstone quarries of Northamptonshire, and that the paper by Hollingworth, Taylor and Kellaway would take its place as one of the landmarks of this century for the structural and stratigraphic interpretation of the Mesozoic areas of England.

DESCRIPTION OF PLATE 3

1. Geological map of the Evenlode gorge and its surroundings, surveyed on the 6-inch scale, 1943-45. Drawn by Mr. W. T. Wright. Figures close to the Evenlode bridges denote height of alluvium above O.D. measured from bench-marks or adjacent spot-heights. Alluvium includes some low-level gravel (p. 105).

BELOW

2. Horizontal profile of the Jurassic rocks forming the north-east side of the valley, showing synclinal and camber structures in "elevation" against the background of the undisturbed rocks drawn in section. Horizontal scale same as map; vertical scale $3\frac{1}{2}$ times the horizontal.
3. Gradient diagram of the River Evenlode and the gravels. For clearness the full thickness of gravel is shown for the Hanborough stage, but for the lower stages only the top surface, from which gravel and/or brickearth often slopes down continuously to the edge of the alluvium. Horizontal scale same as map; vertical scale $3\frac{1}{2}$ times the horizontal.

TERRESTRIAL HEAT AND EARTH MOVEMENTS

By A. J. BULL

[Received, 7th December, 1945.]

[Read, 26th January, 1946 (before Midland Group).]

THE earth has a solid crust; which, however, gives hints in places that there are hidden fires beneath. The beliefs of ancient peoples of hot places below have been amply confirmed, for such temperature measurements as have been possible show an increase downwards; there is hot material to feed the volcanoes; and the earth has a core which does not transmit distortional earthquake waves presumably because of its high temperature.

The rocks of which the crust is composed have been divided roughly into those which are heavy and basic and constitute the sima, and those with an excess of silica which are not so heavy, the sial; roughly they are basaltic and granitic. The sial masses rest on or in the basaltic layer and are the continents. Seismic observations have indicated that there are discontinuities in the crust of the continents, and an upper granitic layer and an intermediate layer above the basaltic material have been recognised. Estimates of thickness have varied, and Daly, for instance, for purposes of argument has taken the upper layer to be 15km. and the intermediate layer as 25km. thick. The actual thicknesses, which no doubt vary greatly, have little bearing on the present discussion. The important points are that the continents owe their height above the ocean floor to the relative acidity and lightness of the rocks of which they are composed; and that by their thickness, poor thermal conductivity, and higher radioactive content, they blanket the heat in and under them.

There is no doubt from seismic observations that not only is the crust solid, but so also are the hot layers immediately beneath it, but the latter are only solid in the sense that they transmit earthquake waves and tidal stresses, and this is the reason that makes isostasy roughly the rule and permits the slow movements of growing island arcs. While at present the crust gives an impression of stability, there are places such as the West Indies and some islands in the western Pacific Ocean where slow movement is taking place; and the geological record shows that movements of the crust on a gigantic scale have occurred in the past.

The earth is losing heat by conduction of the internal heat through the crust, and is gaining heat from the radioactive elements Uranium, Thorium, and Potassium. The earlier measurements of radioactive heat were made on acid rocks, and they indicated that the heat gained was greatly in excess of that lost by radiation

into space, and some quite unjustifiable conclusions were drawn. It was soon found that the more basic rocks contained less of these elements ; but in spite of all the corrections that have been applied there remains the embarrassment that the heat coming through the earth's crust would appear to be less than the heat gained from radioactive elements. This embarrassment is more particularly felt by those who for other reasons consider the earth to be cooling and contracting. In order to overcome the difficulty it has been usual to assume either that the radioactive elements are concentrated in a thin layer only 30km. or less thick near the surface or that the radioactive content falls off exponentially, and in the latter case a suitable selection of mathematical constants permits the earth to be in a cooling condition. The question has been carefully discussed by Prof. Holmes [13*], who has shown that, while there is presumably less radioactive heat developed in and below the crust than the measurements of surface rocks would indicate, there is little reason to assume the earth to be cooling.

The old idea that the earth is cooling requires the interior to shrink, so that the solid crust has to accommodate itself to a smaller area, and in consequence has to fold or break. Such folding must proceed *pari passu* with the contracting, and the folds should form a network of simple anticlines and synclines ; such a structure does not, however, dominate crustal tectonics [4]. Among the difficulties to the acceptance of this hypothesis is one cited by Prof. Holmes [14], that if the earth is cooling, then its volcanic and mountain producing activities should be declining, whereas the reverse would appear to be the case. It has not been shown how the existing tectonics can result from contraction, and large areas are undisturbed or may even have been in tension for long periods of geological time.

If on the contrary one accepts the results of measurements that the radioactive heat is at least as great as the heat lost by conduction through the crust, then there must be some means by which any surplus heat can escape, for the geological record indicates that there have been no extreme changes in surface conditions since Cambrian times. This accumulation of heat in and under a large continent will eventually result in the material, particularly the more basic material, becoming sufficiently plastic or fluid to move, and such movement would be outward from the middle of the continent to the hot, but not so hot, material under the oceanic crust. It is on this supposition that the following schemes are discussed in relation to existing tectonics.

GONDWANALAND

The case for the dismemberment of Gondwanaland is well known. The same *Glossopteris* flora indicating tundra conditions has been

* For List of References p. 124.

found first in India, then in South America, South Africa, and Madagascar, in all of which places it is preceded by late Carboniferous glacial deposits, and also in E. and W. Australia and Tasmania.

This flora suggests rather cold conditions, and its uniformity requires a constancy of climate quite unattainable in the widely separated places where the fossil plants now occur. They must have grown on one continuous surface, which was not interrupted by natural barriers such as seas or mountain ranges [11]. The earlier geological histories of these regions appear to correspond in a remarkable manner from the Silurian up to the Permo-Carboniferous glaciation, which produced the Talchir Tillite of India, the Dwyka Tillite of Zululand, and an identical tillite in Patagonia. The *Glossopteris* beds rest on this tillite. The earlier beds are marginal on the continents, but they are absent from some of the present-day coastlines, namely those of Africa, peninsular India, and the south of Australia. These coasts Du Toit regards as being the lines of fracture where the original Gondwanaland broke up. There are beds in Antarctica which are believed to be identical with the Gondwana series, and this continent also may have been part of the original Gondwanaland.

Thus there is evidence of the dispersal of a huge continent, of which Africa was once the centre, and it has been argued that after a very long period of comparative quiescence the heat accumulated under the huge continent was sufficient to soften the rocks on which it rested ; and that a convection current moving out from the central part which is now Africa carried the other portions to their present positions [2].

One might expect the residual central continent, Africa, to show signs of having been in tension, but the evidence as it stands does not support this. The opinion has been held that the structure of Africa with its rift valleys showed it to have long been in tension. Later it was argued that rift valleys had resulted from compression, and that Ruwenzori had been pushed up when the rifts were pushed down [18]. This conception has received support from the gravity survey by E. C. Bullard [7], who found that the gravity was low in the rift valleys, while being nearly normal on the plateaus. From this it has been presumed that blocks of sial have been pushed down by compression. It is interesting to note, however, that Dr. Dixey now regards the bordering scarps of the rifts as fault line scarps, and the earlier faulting may have been tensional [10].

ISLAND ARCS

Rows of islands arranged in long arcs are a feature of the western Pacific and of the West Indies. Some of them are backed on the concave side of the arc by a continent, others have no obvious relationship to land. So far as I can ascertain from published

descriptions, the structure is generally simple ; it is essentially a long anticline of which the higher and more folded parts come up out of the waves as long domes. In the larger masses building up these arcs the tectonics doubtless become more complex, for instance Meinesz speaks of a fold through the long line of the Banda Arc, but mentions the presence of "overthrust sheets." The rows are sometimes double with a synclinal trough between them, but only parts of the outer second ridge may show above the sea ; this is the case with the Kuriles and also the Banda Arc, which has islands standing out from the main arc at both ends, while between them off Java there is a submarine ridge, Fig. 5.

Other characteristics of island arcs are that volcanoes commonly occur on the concave side, and the line of islands may not be a simple anticlinal ridge, but a series of anticlines arranged *en échelon*. This is the case with the elongated islands of the Kuriles, and in the Ryukyu arc between Japan and Formosa there are overlapping echelon folds at both ends where the curvature is greatest [6].

The echelon structure has been cited as evidence of subcrustal currents, and this gives the most ready explanation of the phenomena. Such a current could carry out the terrigenous deposits of a continent and fold them against the resistance of the ocean floor. It would only be when light material was involved in the folding that the ridges would come up to form islands ; the Marianas and the Palau Islands, for instance, are the peaks of a huge arc. Behind the rising current the crust would be in tension, and so give the conditions for the injection of hot material from below, and when sialic material is involved the crust may come above the waves ; lavas from such volcanoes are usually andesitic.

Ocean arcs without a land backing are probably due to subcrustal currents resulting from differences in radioactive content ; for it is unlikely that the material of the earth is thoroughly mixed, and the unequal liberation of heat will produce convection currents in the plastic material under the crust.

Measurements of gravity [16] have shown that there is a belt of negative anomalies outside the Caribbean Arc and also outside the Banda Arc along the line of Babi, Nias, the submarine ridge off Java, Timor, and curling round northwards between the Moluccas and the Celebes, thus indicating that there exists an excess of light material in the crust along this line. The work in the East Indies was carried out by Meinesz under great difficulties. He states that this belt of low gravity is 100 miles in breadth and 5,000 miles long. In addition there are two lines or fields of maximum gravity in parallel orientation to the minimum line, one is inside along or close to the line of volcanoes, and the other is outside in the Indian Ocean, Fig. 5 [12].

The convection current hypothesis again offers an explanation. If we suppose that a convection current of hot material is spreading



FIG. 5.—This gravity map of the Banda Arc is after P. Evans and W. Crompton following F. A. Vening Meinesz. It shows the arcuate form of the islands, with an outer arc comprising Babi and Nias in the west and Timor in the east which together with a submarine ridge off Java form the gravity minimum line. Parallel to this in the Indian Ocean is a line of high gravity, while another belt of high gravity follows closely the line of volcanoes in the island arc.

out from a region in the South China Sea or possibly initially from Asia, then it would carry outwards on its back any light sial masses, which it would fold against the heavy crust of the ocean floor. The folds would be simple in character in the early stages, and along the line where the folds of sial are thickest, Fig. 6, there would be negative gravity anomalies. Meinesz expressed the opinion that the only plausible explanation was that there must be an accumulation of light material in the crust along the line. This point is emphasised by Holmes ([14], p. 405), whose diagram shows the deepest part of the light root below the submerged ridge off Java. An idea has crept into the literature that some unknown

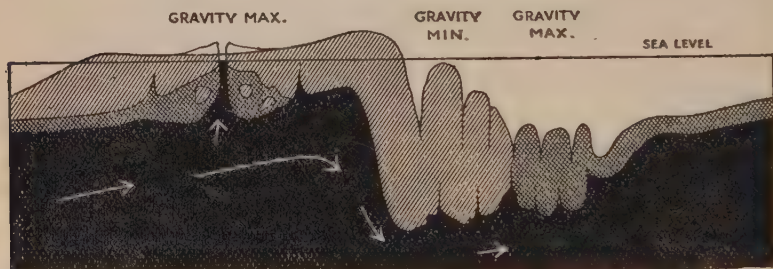


FIG. 6.—DIAGRAM OF A RADIAL SECTION THROUGH AN ISLAND ARC showing the results of a subcrustal current dragging light material outwards from a hot centre. The light but relatively stiff sial will be moved outwards to form an arc and pressed against the basaltic crust of the ocean floor. Both will fold and thicken. The folds of the sial of the ocean floor being heavy will produce an excess of gravity, while conversely there will be a gravity minimum line above the folded and thickened sial. As the folded mass extends downward into the plastic sima, so it will present an obstacle to the current, which will thus exert a greater force on it than on the flatter sial behind it; and in consequence there will be tension in the crust immediately behind the folds. This tension will permit the hot material from under the crust to rise, melting some of the sial as it does so, and form the line of volcanoes behind the rising islands, then as this sima solidifies so it will form a relatively heavy rock mass. This conception explains the line of gravity maximum which follows the line of volcanoes of the Banda Arc, Fig. 5. That the arc of folded light material is rising in isostatic adjustment is shown by recent coral reefs being high on the hills of these islands.

force is holding down this light material, but the recorded observations indicate rather that the arc of light material is rising, for there are recent coral reefs high up on Timor, and the whole arc is probably moving outwards from its centre and at the same time rising towards isostatic adjustment in the small movements that give rise to earthquakes. Meinesz states that the majority of earthquake centres are in or near the strip of negative anomalies. Further, he agrees with Hobbs, Brouwer, and others that these active island arcs are early stages of mountain building; while this is

possible I would qualify this idea by pointing out that in the cases of the Carpathians, the Alps, and the N.W. Highlands the light sediments have been "thrust" upon an older foreland ; here there is no foreland.

Meinesz also expressed the idea that the line of volcanoes was due to tension in the crust, and that the heavier material coming up from below as a liquid then solidified and produced the line of gravity maximum. How this may come about is indicated by the convection hypothesis, for the subcrustal stream impinging on the downfolded sialic material would move it outwards at a greater rate than the flatter crust behind it, and so produce tension immediately behind the folded line. The outer field of maximum gravity is also explained, for if the outward moving sial ridge were pressing against the sima of the ocean floor, the latter would be thickened, and so produce a higher gravity above it.

W. M. Davis [9] from his study of the coral reefs of Fiji considered that the evidence "clearly suggests the westward propagation of a broad shallow wave-like deformation of the ocean floor, in which the wave-length, from crest to crest, is to be measured in several scores of miles and the wave height, from trough to crest, in only a few thousand feet. In other words, the changes of level in the several belts all appear to be caused by the slow westward migration of a broad and low ocean floor anticline, preceded and followed by shallow ocean floor synclines." To account for such a phenomenon one may suppose that under the ocean crust a current was moving a mass of relatively light material westwards, and this buoyed up the crust to form the moving anticline.

GRAVITY SUBSIDENCE AND FOLDED MOUNTAINS

It is typical of folded mountain ranges that they consist largely of sediments. Such sediments have often been deposited in a trough ; and while the weight of the sediments has helped the trough to sink isostatically during the process of accumulation, the initiation of the sinking can only have been produced, as Joly has stated, by heavy minerals forming under or in the crust. To provide material for the sediments there must be high ground at the sides of the sinking trough, that is, a typical case would be a sea between two continental masses of sial. Under these conditions the denudation of the continental lands would result in their materials being washed into the sea and deposited on the sea bottom, so long as the sinking continues.

It is here assumed that the radioactively produced heat blanketed by the thick continents would eventually soften the rocks sufficiently to permit a convection current of hot and plastic material to come out from under each continent ; at the same time in the general softening of the subcrustal material the heavy rocks under the

sinking deposits would take part in the movement [1, 3]. The moving material would carry the deposits above it towards the sinking middle of the trough, some of them to be carried down in the wake of the still heavy rocks, and the rest to be heaped into folded masses, which would pile up above the central line of sinking, Fig. 7. It would be at this stage, when the sedimentary rocks were piled above the general level of the earth's crust, that sheets would slide off as nappes under the force of gravity; and the front edges of these would develop imbricate structure as they came on to the lower ground. Such is the case with the Moine Schists in the N.W. Highlands of Scotland and the northern edge of the Jura Mountains [5, 17]. Isostatic adjustment would be relatively rapid for the crust would be broken. Water entangled in the sediments might well be dragged down in these movements, in which case it would make its presence felt later in volcanic explosions and hot springs. The original heavy minerals would be melted and reconstituted, and the sinking portion replaced by light-folded sediments, which would buoy up the rocks above as mountains.

It has often been assumed that the folded mass sinks first and then rises. Such rising would certainly be a late phase when the mountains were being removed by denudation, but the very existence of nappes is here regarded as a proof that the inclination of the beds has been high enough for movement to take place under the force of gravity, the only known force that can move a sheet of rock bodily.

It is interesting to note in connection with these ideas that the Carpathians have strikes which are discordant with those of the rocks on which they rest. Again in the case of the Western Alps the three series of nappes which compose these mountains rest upon a Palaeozoic platform or foreland; so that the sediments which were deposited to the south of the platform must have been raised so that nappe after nappe could slide to the north under the force of gravity.

CONCLUSION

The foregoing is a contribution to the idea that the mountain building force is merely gravity, and that the disturbance calling it into play is the unequal heating of subcrustal material by radioactive elements. It would appear that the idea does accord with some existing tectonics.

Two apt quotations may be given here. Joly's opinion was that "the broad physiographic features of the globe—are involved in the events arising out of isostasy and the radioactivity of the rocks" [15]; and at a later date Holmes has stated that "In a body like the earth gravity tends to maintain equilibrium and stability. The only known agency capable of disturbing this equilibrium to any important extent is heat." [14].

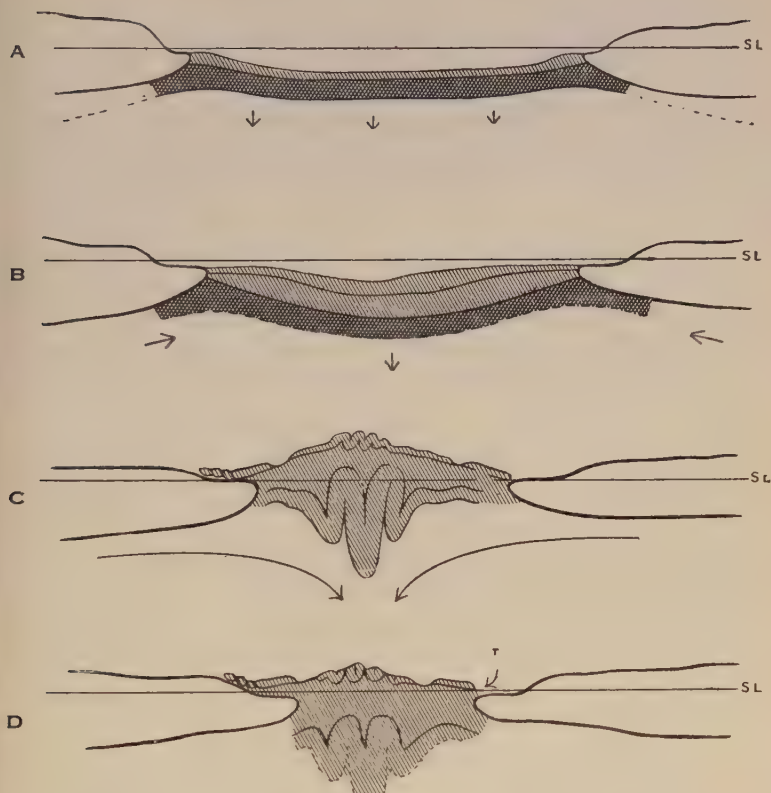


FIG. 7.—STAGES IN THE DEVELOPMENT OF A GRAVITY SUBSIDENCE.

A. This shows a subsiding portion of the crust between two continents, and upon this sediments are being laid down.

B. The subsidence has continued, and the sediments have increased in thickness.

C. With the more rapid sinking of the heavy rocks under the subsidence and the hot material coming out from under the continents the sediments are heaped together in the middle, then from the raised centre sheets of rock slide towards the edges under the force of gravity, and the edges of these sheets of rock or nappes develop imbricate structure where they meet obstacles. At this stage isostatic adjustment would be easy, because the crust is shattered, and the folded mass will sink.

D. At a later stage, when the upper folded rocks are in process of denudation, the folded mass is rising in response.

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FIELD MEETING AT UPNOR, KENT

Saturday, 20th July, 1946

Report by the Director : D. L. Searle

A PARTY of 16 assembled at Strood Station with the object of examining the fine sections in the Lower London Tertiaries and the Pleistocene deposits, which were last visited by the Association in 1924 [1*].

From the station the party climbed to a vantage point above Crown Quarry, overlooking the lower reaches of the River Medway. The Director pointed out the chief features of the extensive view, commenting especially on the even-topped skyline formed by the North Downs, which had been bevelled by the early Pliocene marine transgression. Fragments of a later (? early Pleistocene) erosion surface, the 200-foot platform, and of various river terraces within the gap were also indicated.

On the hill above Crown Quarry good sections of river gravels were seen varying from a foot to as much as nine feet in thickness. The gravels in the thicker section showed well-bedded light and dark bands, the former consisting of reddish-brown sand and silt and the latter of well-rounded pebbles of chert and flint in an irregularly graded matrix. Below the gravels occurred a layer of coombe rock about 6–8ft. thick. The gravels represented the 100ft., 50ft. and 25ft. river terraces of the Medway [2], but it was found difficult to trace the boundary between these terraces owing to the downwash.

The party then walked northward across the misfit Islingham stream to Tower Hill at the southern end of which the basal Thanet sand with the Bullhead bed caps the chalk. One interesting feature is that the chalk, in places, is strongly wind-blasted by the fine sand blown down from the overlying beds. On a windy day this fact can be fully appreciated. A hundred yards to the north the party stopped to examine the junction of the old Medway course with the Thanet Sand. This has been described in detail by Hutchings [2]. Small fragments of bone were obtained from the gravel deposits.

After lunch at Upnor the party was joined at a standing stone by the deputy commander of the training ship *Arethusa*. He gave an interesting account of the history of the ship and of the earlier *Arethusas* and between us we tried to decipher the words "London Stone marked 1240 God preserve the City of London," which occurs on the 6in. O.S. map. The only part of the inscription which we could not check was the date, 1240. However, we were

* For List of References see p. 127.

brought back to earth again by a remark made by the naval officer that in a few days' time he was going to spend his leave in the neighbourhood of the Craven Faults! Apparently the Navy knows as much about the land as it does about the sea.

After passing one of the earlier *Arethusa's* figureheads, which is only equalled by those at the Valhalla in the Isles of Scilly, the party walked along the beach at Lower Upnor towards the Hoo, where the salt marsh flats were well exposed. Here also was seen the remains of the brickearth of the 25ft. terrace above which occurred large masses of slipped London Clay full of small irregular and twinned crystals of selenite. One section behind a storage tank (built for D-day operations) shows slipped London Clay resting on brickearth and terrace gravels, giving a rubbly appearance, together with a sandy variety of the Oldhaven Beds, containing typical shell fragments, chiefly *Cyrena cuneiformis* and *Corbula regulbiensis*.

Returning to Upnor the party struck inland and made a circuit of Beacon Hill from which fine views were obtained of the salt marshes of the mouth of the Medway, of the valley occupied by the Islingham stream, and of the Tertiary escarpment above it.

Descending the hill the sandpit of the Naybro Stone Company was visited. This fine section of Thanet Sands, Woolwich Beds, and Oldhaven Beds differed little from that described by Prestwich nearly 100 years ago [3], but the Director referred to certain points of detail gained by Mr. M. C. Berdinner during an intensive study of the mechanical components of the different beds.

In particular the conditions under which the various horizons were deposited could be inferred from the variations in grading which they showed. The mechanical analysis of the Thanet Sands produced curves closely comparable with those given by beds known to have been deposited during a marine phase of medium depth. The incoming of coarser material in the Upper Thanetian Beds indicated a shallowing of the sea. On the basis of mechanical composition only, the following conditions of deposition were found for the various horizons of the Lower London Tertiary Beds exposed at Upnor:—

London Clay	...	...	Marine (deep)
Oldhaven Sands	...	...	Marine (shallow)
Woolwich Shell Beds	...	...	Lagoonal (shallow)
Woolwich Sandstone	...	...	Estuarine (deltaic)
Woolwich Pebble Bed	...	...	Marine (shallow)
Upper Thanet Sand	...	...	Marine (shallow)
Lower Thanet Sand	...	...	Marine (medium depth)

This clearly shows the progressive shallowing and deepening of the area during Tertiary times, and agrees with the faunal evidence obtained from these beds.

Ample time was allowed for collecting ; although fossils were numerous the variety was scarce. The chief types collected were : *Cyrena cuneiformis*, *C. cordata*, *Ostrea tenera*, *O. bellovacina*, "*Potamides*" *funatus* and "*Melania*" *inquinata*.

A vote of thanks was proposed by Dr. A. J. Bull and, in his reply, the Director thanked Mr. W. Smith for his services as secretary. The party then returned to the Ship Inn, Upnor, for tea.

As time permitted after tea, the party attempted to storm Upnor Castle, but found that access was denied to the public. The return to Strood Station was made via Frindsbury and Crown Hill.

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SOME GRAVELS AND GRAVEL-PITS IN HAMPSHIRE AND DORSET

By J. F. N. GREEN

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IN the course of mapping the terraces of the rivers near Bournemouth and, in less detail, those of the Axe, Otter and Dart, some study of the river deposits associated with them has been inevitable. The possibilities of archaeological dating have been constantly borne in mind, and in a recent paper [1*] particular attention has been drawn to the location of gravel-pits in this connection.

The nomenclature of river deposits is liable to misunderstanding. Textbooks give the name "alluvium" to all waterborne river deposits, whatever their age or texture. Geikie's textbook (3rd Ed., 1893, p. 393) describes seven varieties. On the other hand the Geological Survey for at least 80 years have regularly used the word for fine-grained deposits of very recent, mostly Holocene age, giving them a distinct colour on the maps, and classed older deposits as "valley-gravel," "plateau gravel," etc., occasionally referring to a fine-grained deposit as "old alluvium."

While "gravel" is a useful and comprehensive term for coarser material deposited by rivers, conveniently covering a range from cobbles to coarse sand, there does not appear to be any similar term recognised for river deposits from medium sand to clay. Lyell uses "inundation mud" for the commonest type. In what follows the writer will use "fine alluvium" as non-committal.

Terrace deposits. It is sometimes suggested that gravel indicates a more rapid river than fine alluvium. No doubt it requires a more rapid movement of water at the point where it is being deposited, but there does not appear to be evidence for an assertion that it necessitates a more rapid river. The process of simultaneous deposition of gravel and fine alluvium was explained by Lyell [2, p. 127 *et seqq*], with his usual lucidity. After pointing out that we have almost always to pass down through a mass of inundation mud before getting into beds of gravel, he writes :

As a rule, when a river attacks and undermines one bank, it throws down gravel and sand on the opposite side of its channel, which is growing shallower and is soon destined to be raised so high as to form an addition to the alluvial plain, and to be only occasionally inundated. . . . Sometimes an island is formed in mid-stream, the current flowing for a while on both sides of it, and at length scooping out a deeper channel on one side so as to leave the other to be gradually filled up during freshets and afterwards elevated by inundation mud or "brickearth."

* For List of References see p. 143.

This process of joint deposition can be verified by walking over recently flooded water-meadows in our southern rivers. A film of mud is seen on the vegetation and on plank bridges ; muddy water is still settling in the oxbows and ditches ; and banks of gravel show on the inside of meanders.

It would sometimes be inferred from papers on terraces and their gravels that the rock bench was cut during a period of erosion and the gravels thereon deposited during a period of aggradation. There does not appear to be evidence for such a process in our graded terraces. Gilbert writes [3, p. 127] :

The current is always swiftest along the outside of a curve of the channel, and it is there that the wearing is performed ; while at the inner side of the curve the current is so slow that part of the load is deposited. In this way the width of the channel remains the same while its position is shifted, and every part of the valley which it has crossed in its shiftings comes to be covered by a deposit which does not lie above the highest level of the water. The surface of this deposit is hence appropriately called the *flood-plain* of the stream. The deposit is of nearly uniform depth, descending no lower than the bottom of the water-channel, and it rests upon a tolerably even surface of the rock or other material which is corroded by the stream. The process of carving away the rock so as to produce an even surface, and at the same time covering it with an alluvial deposit, is the process of planation.

It can sometimes be seen at low water in our southern rivers, most easily perhaps in chalk streams, that the gravel is in contact with the solid rock. The coarse material, being transported by traction, must there effect some downward erosion, especially in flood-time, when the fine alluvium, transported by suspension, is being spread over the flood-plain. The result is a veneer of gravel, capped with fine alluvium. Some evidence will be given later, when discussing individual gravel-pits, that this is the actual condition. In the Boyn Hill plain, on which much of Bournemouth is built, it can be seen in the cutting for the railway crossing it, that, wherever the plain is level the veneer is only 6-10ft. thick ; and this is supported by excavations. The veneer is conveniently termed "terrace-gravel."

Gilbert's account which, in the writer's experience, applies in all respects to English rivers, is reinforced by evidence that our larger terraces have been constructed by a succession of meanders. The rough calculation [1, p. 96] that a series of eight meanders might be involved in the formation of parts of the Boyn Hill terrace has some confirmation from direct observation. An area below Watton's Ford, south of Ringwood, in the Hampshire Avon has been examined. Being just below a nick-point, the effects of lateral erosion are well preserved. The measurements make the difference of level between successive meanders between a foot and a foot and a half. The longitudinal slope is exceptionally steep and the meanders smaller than normal.

In such a river as the Avon water-borne deposit is being moved and re-arranged along the whole course. That part of it mapped as alluvium is usually water-logged and is often irrigated. At intervals along the river occur discontinuities termed "nicks." From these nicks or, when they are complex as on the Chalk of the river Test [5, fig. 17], from their upper parts, an elevated terrace can be followed and mapped downstream, becoming dissected as it diverges more widely from the present floodplain. If the Survey maps of the Bournemouth area are compared with the maps prepared on different lines by the writer, such as Plate 5, vol. lvii, of our *Proceedings*, it appears that immediately east of Wimborne the valley gravel of the Stour is in the Second Taplow and Staverton stages, graded to sea-levels about 50 and 20 O.D. These are known to pass into alluvium at nicks above Blandford and Corfe Mullen respectively. A mile below the nick at Canford, the Second Taplow gravel is promoted to plateau gravel.

At Longham the Christchurch terrace-gravel, which so far down has been mapped as alluvium, becomes valley-gravel. On the Hampshire Avon there is a similar change near Bisterne. On both rivers the change in nomenclature takes place when the height of the bounding bluff rises to more than 2ft. In both valleys the First Taplow gravel, graded to the same sea-level as the Second Taplow, is plateau gravel in the Bournemouth sheet; it is valley-gravel in the Ringwood sheet.

Miss Boswell's accurate measurements of the river Test [5] show that alluvium constantly passes into valley-gravel. If the terraces are correctly identified, the gravels of the Sleight, Boyn Hill, Iver and Taplow terraces all pass from alluvium, through valley-gravels and terrace-gravels, to Plateau gravels.

The writer finds it difficult to draw a definite boundary between alluvium and valley-gravel, especially as the former is changing into the latter at a rate which, geologically, is rapid. Bromehead's demonstration [4] of the movement of a nick on the river Wharfe of 200yds. in 1500 years is an example, as the boundary between alluvium and valley-gravel has presumably moved the same distance. The movement of Watton's ford, near Ringwood on the Hampshire Avon, has been more rapid; at Bemerton, west of Salisbury, a ford across the Nadder is now 300yds. above the Roman road.

Undoubtedly the Survey distinction is of fundamental economic importance and the value of their maps to industry is increasingly great.

On the other hand, as often pointed out in the Survey Memoirs, a distinction between valley-gravels and higher river deposits is not easy to maintain, except where, as north of London, a glacial episode can be shown to intervene. Even then it fails on tracing up a river.

In discussing terrace-deposits, it is thus necessary to treat

alluvium as merely the upper part of a continuous sheet of deposit, which, when it begins to be naturally drained as it diverges from the present floodplain, is termed "valley-gravel"; with continued divergence, is often termed "terrace-gravel"; and, when it reaches a considerable height above the river, often about 50ft., is termed "plateau gravel."

Bay delta deposits. There is another type of accumulation to be considered in the lower parts of our rivers. When a valley is drowned by a relative rise of sea-level, the river drops its gravel as soon as it enters the wider expanse and initiates the building of a bay delta. Much of the fine mud is carried on and deposited on the bottom of the estuary. After a time the foreset gravels advance over the bottomset mud. As the delta grows, fluvatile aggradation begins behind it and may absorb the available supply of gravel, in which case much of the delta will consist almost wholly of fine alluvium as in the Thames estuary. The earliest of these bay deltas so far described in this country is that of intra- or pre-Boyn Hill age in the ancient channel of the Thames at Clacton. There may be an older one at St. Agnes, Cornwall [22, p. lxxxiii]. Owing to special circumstances the post-Taplow Muscliff delta is exceptionally well preserved in the Bournemouth rivers. The latest delta is well known from excavations for docks and, in the south-west, for tin-mining.

The delta has a level surface near high water of spring tides. At some point in the rear of the delta-face, the river begins to deposit alluvium on the foreset beds and to build a new profile. It seems probable that this point is near tidehead, but the writer does not know of any satisfactory measurements.

In many cases the delta advances, not only over older terrace-gravel, but over accumulations of wash, solifluction material or aeolian deposits. This may be expected to be particularly evident when the bay delta is filling a gorge. In whatever way the drowned valley may be filled, the top of the filling will be re-arranged by normal river action. "Bay delta deposits" may be used comprehensively to include all the various materials that go towards filling a drowned valley.

A notably clear example has been described by Burchell [6] in the Ebbsfleet valley. Excavation determined Coombe rock at the base. On this, at about 22 O.D., lay fluvatile gravel, which the writer would consider to be Staverton terrace-gravel. Above this is several feet of loess, weathered at the top. On this, solifluction gravel, covered by more loess, represents the period of the "Upper Buried Channel." Then a temperate shell-bed, associated with fluvatile gravel, attains 39 O.D., the level of the Muscliff delta.

In the case of these bay deltas, separation of a period of erosion and a period of aggradation is plainly legitimate. The division

may be marked by an old soil. A subsequent fall of relative sea-level will give rise to an elevated terrace morphologically much like an ordinary river terrace.

The horizontal segments at the seaward end of certain river terraces have been ascribed by the writer to tidal action during a prolonged standstill [1, p. 92]. So far as his experience goes, the gravels do not differ in character from other terrace-gravels.

Bluff deposits. A third type of gravel accumulation is that formed in bluffs. "Bluff" is used here to cover the area of increased slope between two terraces. Most of this may be comprehensively termed "wash," but it includes scree and slumped material. Solifluction may play an important part. In areas where wind-borne deposits occur, they may be expected to occur extensively in bluffs. Wind tends to scour dust from flat level surfaces, but to accumulate it in hollows and along bands of discontinuity. Snow may often be seen arranged thus after a storm. Miss Arber [7] has described the choking of ditches 6ft. deep in two or three hours by dust storms near Ely, and is informed that the dust collects in drifts along hedgerows and raised dykes. Many of the French sections showing deposits of loess are obviously in bluffs.

The bluffs also include the disturbed terrace-gravel of the "waxing slope" of Wood [8], that is, the convex upper portion of the sigmoid profile. When flint gravel is resting on clay or sand, the waxing slope is formed, not by surface erosion, but by water flowing out and eroding at the gravel base. This may be seen near Bournemouth and may be true also when the base is chalk.

Another marked characteristic of the bluffs is channelling, producing a furrowed solid base. An example is the cliff section of a bluff figured in the second edition of the Bournemouth Memoir [9, p. 58]. Excellent sections may often be seen in railway cuttings across bluffs. A large channel may be worked as a pit. The writer is indebted to Mr. J. B. Calkin's notes and photographs for information on such a pit at Charminster, Bournemouth, still partly visible. Channelling is equally marked within the bluff deposits, especially where a climatic change has led to erosion of a loamy or clayey sheet by gravel wash.

Economical production of gravel requires a high working face, naturally drained. Loading is then downwards, movement of tracks and gear is reduced and the area to be purchased is at a minimum. In consequence the largest pits are, in the writer's experience, always in bluffs. Where land is cheap, pits of some size may start in bluffs and run along terrace-gravels. Examples may be seen in the barren moorlands near Poole and Wareham. Pits sunk in a terrace surface are usually small, shallow and short-lived. Such are often opened for casual repairs near roads crossing terraces.

In the areas studied by the writer at least four-fifths of the pits, including all the largest, are opened in bluffs.

With regard to the distribution of these three types of deposit in the south of England, the bay deltas only occur in the lower parts of the valleys. They seem usually to be found in gorges. Terrace-gravels are found on the flat parts of terraces. The proportion of the area with terrace-gravel to that with bluff gravel varies with the size of the terraces. In the Bournemouth district, leaving small streams out of account, there is estimated to be between five and 10 times as large an area of terrace-gravel as of bluff deposit ; in the Thames the proportion must be higher.

To illustrate the manner in which morphological methods can be used to elucidate the relations of gravels of archaeological interest, an account is given of four differing types of pits, namely, the great ballast pit at Broom, in the Axe valley ; a small pit at Hordle, Hampshire ; the Stoney Cross pits, near Lyndhurst ; and the series of pits near Sleight in the valley of the Dorset Stour.

Broom. The ballast pit, a noted source of palaeoliths, is in Dorset, three miles north-east of Axminster, though the hamlet of Broom is in Somerset. It has been derelict for several years. The pit, which covers an area of about 25 acres, is opened in the side of the Axe valley, at its junction with the Blackwater valley, where it rises to a terrace with lower edge 195–200 O.D. Not far south is seen above this a conspicuous flat at 240 O.D. A large flat at the same height is on the opposite (west) side of the valley. A series of similar flats can be traced down the valley to a little above 200ft. above the sea, and evidently belong to the Ambersham stage found in other western rivers. The most marked terrace below this has been followed upstream from Kilmington, four miles south-west of Broom, where it is about 150 O.D., *i.e.*, 80ft. above the river, and has yielded implements. At Weycroft, a mile and a half from the pit, it is 157ft. ; and at Coaxdon, half a mile farther up, at 160ft. This terrace is in the position of the Boyn Hill. If continued to Broom it would be about 163 O.D. It follows that the floodplain of the Axe near the pit, which is about 138–140 O.D., must be in the Iver stage ; and the terrace at 200ft. must be the Sleight terrace.

The country rock is Gault clay. The gravels are repeatedly said to be over 50ft. thick. The best description of them is by J. Reid Moir [10], but, like all other writers from D'Urban in 1878 [11], he omits to mention that the section is composite. He stated that the lowest part consisted of 17ft. of unstratified gravel. Above came 8ft. of stratified gravel, on which rested 25ft. of "tumbled" (Moir's word) gravel with a clayey matrix. The stratified gravel is the source of unrolled Acheulian and Clacton III implements. Its top level is near 165 O.D. Moir correlated the gravel below it

with Kimmeridgian Chalky Boulder-clay, that above it with Upper Chalky Boulder-clay.

The pit is now much overgrown and the five tramways shown on the Ordnance map have been pulled up. It is, however, easy to see that the gravel was first opened up by a broad-gauge way connected with the railway near the pit, starting at the level of the line, about 146 O.D. and running along an early face, some 160yds. from the present face, with a sufficient slope to allow loaded wagons to run easily to the railway. This tramway was banked up on part of the Axe floodplain, and it is evident that the whole of the lower gravel must have been near the mouth of the pit and was measured from the floodplain level.

The first tramway appears to have ended at the base of the stratified gravel. No exposure of this gravel is now seen at the main face, but a fair one occurs in the road immediately south. It

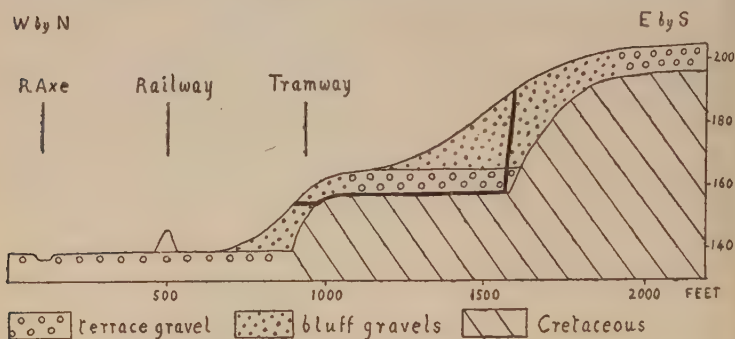


FIG. 8.—SECTION OF GRAVEL-PIT AT BROOM.

is a clean river gravel. From the contour of the pit it is plain that the greater part of it was worked along the base of the stratified gravel.

The present face of the pit is over 30ft. high, but is largely talus, which conceals the stratified gravel, if any is now present there. The uncovered part is a mixture of coarse gravel and clay with a rudely stratified appearance. There is a stoneless band a few feet from the top, estimated from below as two feet thick.

According to the man in charge of Broom level-crossing, who had an intimate knowledge of the pit, it was abandoned because the gravel became too dirty to be worth working. The nature of the face justified his statement and it is probable that the best gravel, *i.e.*, the stratified river gravel, had been nearly or quite worked out.

The gravels may be classed as follows :—

The lowest, from 140–157ft., are bluff deposits in the Boyn Hill–Iver bluff.

The stratified Acheulian gravel, from 157–165ft., is Boyn Hill terrace-gravel.

The clayey gravels, 165–190ft., are bluff deposits in the Sleight–Boyn Hill bluff. The stoneless band marks a climatic oscillation during bluff construction.

Contours suggest that the Boyn Hill terrace had extended perhaps 50yds. beyond the bluff.

The Sleight terrace-gravel is not exposed in the pit.

This interpretation is figured in the accompanying section (Fig. 8).

The unusual thickness which has been assigned to the gravel at Broom is thus due to summation of sections shown in successive banks for working. An example of an estimate similarly amplified is the gravel at Kilmington, also in the Axe valley, which has been supposed to be 80ft. thick. The place has not been closely examined, but in conversation with the under foreman in 1935, it appeared that he had a clear idea of the limited form of the deposit, which he described expressively as a “hump.” From his information it is unlikely that a vertical thickness could be obtained of as much as 35ft.

Hordle. A small pit, 300yds. south-west of Hordle Church, Hampshire, is at the 100ft. contour in the side of a minor valley draining to the Solent, two miles south. The Boyn Hill terrace of the former Solent river is widespread a quarter of a mile to the north-west; the Iver terrace is well developed to the south. The country rock is clay of the Headon beds, and the district is cut up by small valleys and so affected by soil-creep that it is difficult to map precisely; but the upper limit of the Iver terrace may be placed about 100yds. south-east of the pit, which is in a waxing slope to the minor valley.

A tripartite division of the gravels in the pit, now exposed along more than 100yds. of face, was recognised by Burkitt [12]. At the bottom is a river terrace-gravel with a well-defined top. It is apparently about 4–5ft. thick, but the base is obscured, the pit not having been worked for some time. The upper part of this gravel is cemented by iron-pan. On it rests sand up to a foot in thickness, lenticularly interbedded with an upper gravel. This is 2½–3½ft. thick, and has a peculiar striated appearance, being largely composed of flattish bits of flint, white patinated, lying horizontally.

There can be no doubt that this upper gravel is part of the fringe of wash from the Boyn Hill terrace. The interbedded sand must go with it, though, as Burkitt noted, it is so rounded as to have a marine or estuarine appearance. This may be ascribed to its derivation from the estuarine Tertiary beds. It is mixed with angular flint chips.

An unrolled late Acheulian and a slightly rolled Levallois II implement found by Mr. Preston in the upper gravel may be presumed to have been washed from the Boyn Hill terrace. Rolled Chellian flints from the Iver river gravel may have passed through several terraces.

Stoney Cross. The village, three miles north-west of Lyndhurst, is situated within the area of Reid's "High Plateau" [13], compared by Bury with the Cornish 430ft. platform, the deposits on which may be correlated with the Westleton Beds. It is considerably dissected, but can be seen to be four miles across, sloping south-west at about one in 300.

West of Stoney Cross an undissected strip of the platform runs for more than a mile south-east to north-west. It is remarkably level, varying only about 4ft. from 373 O.D. From it a "knife-edge spur" projects nearly due east for a mile, sinking halfway to 342, and then rising to 355 O.D., before descending to the valley of the Cadnam river. The spur was utilised by a Roman road, now part of the main London road.

The country rock is Barton Clay, with a little Barton Sand on it in the eastern part of the spur. Shallow gravel has been much dug near the sides of the road, especially at the eastern end. Numerous springs come out beneath the gravel and can be seen to bring up mud. The pits, which do not seem to have been anywhere more than 8ft. deep, have not been worked lately. The two best sections now to be seen show respectively 1½ft. of irregular gravel on 3ft. of loam with scattered stones; and a few inches of stony soil on 3ft. of loam, passing down into 3ft. of unsorted gravel. The coarse gravel consists of flint with some chert; the small components include quartz. No far travelled stones were noted.

Three implements, obtained by Dr. Longstaff, have been figured by R. Smith [14], who described them as of Chelles character. An account of their discovery is given by Crawford [15]. One was from a depth of 5 or 6ft. near the east end of the spur; the other two were 100yds. farther west, apparently 3ft. deep.

Erosion in this terrain is rapid and till near the end of the Pleistocene, perhaps into the Holocene, the area of the spur must have been part of a plain rising from 373 O.D. to about 385 O.D. Whatever the original nature of the deposits of the plain—in the writer's opinion, they were marine—they have been subjected to the vicissitudes of the whole of the Pleistocene period; sometimes frozen to a great depth, sometimes afforested. Forest conditions involve much disturbance of the surface by pressure and decay of roots, and by fall of trees. The writer has noted a hollow 5ft. deep where a tree has been uprooted. These incessant surface changes have culminated by the gravel being dropped 20 or more feet by sub-gravel erosion. There has then been every opportunity

for implements left on the surface, say, halfway through the Pleistocene, to get buried 5 or 6ft.

These considerations do not apply to a find at a lower level half a mile to the south. The pit, which is in a dissected area, is overgrown, but the presence of the Sicilian platform nearby supports Bury's suggestion that the implement figured by him (15A) came from a marine gravel near 300 O.D.

Sleight. The complicated gravels of the Sleight district west of Wimborne, Dorset, are connected with the "Sleight plateau," a flat over half a mile long and averaging about a quarter of a mile wide. (See map, fig. 9.) It is part of the terraces of the Stour, now flowing three-quarters of a mile north with a floodplain level

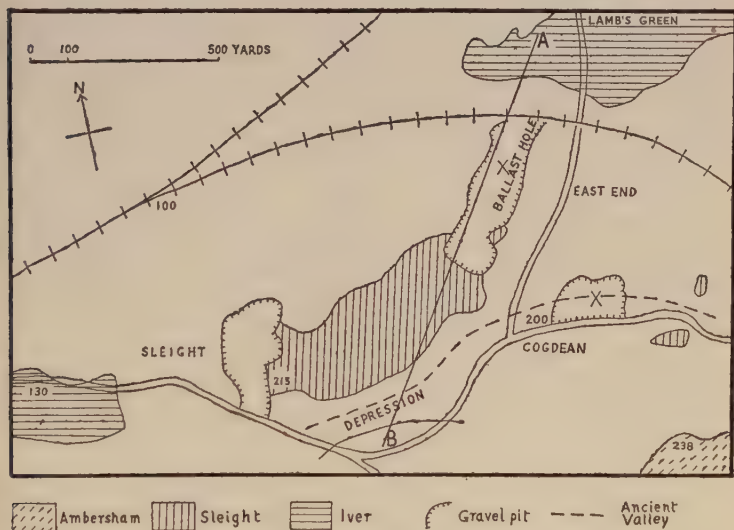


FIG. 9.—GRAVELS ON THE SLEIGHT PLATEAU.

of 64 O.D. The level summit descends from 215 O.D. on the south-west to about 208 O.D. on the north-east. Northwards it slopes gently in the waxing slope for some 6 or 7ft. and then more steeply for at least 70ft. at an angle averaging one in 12. Towards the north-east and also to the west the bluff falls to the Lamb's Green terrace of the Survey [9, p. 56], correlated with the Iver terrace. This slopes approximately from 130-120 O.D. East and west the plateau is isolated by tributaries of the Stour. Southward the plateau is bounded by a depression running east and west with a minimum depth of 3ft. This depression is continued to the east between two fragments of the Sleight terrace, the total distance for which it can be traced being three-quarters of a mile. South

of this depression begins the upward rise to the Ambersham terrace, here at near 240 O.D.

The gravels, mostly flint, rest on a silty clay on the east of the plateau, which passes on the west to a fine sand. These seem to be passage beds between the London Clay and the Bagshot Sands.

The most important of the pits surrounding the plateau was formerly the "Ballast Hole" in the northern Sleight-Iver bluff. It is now worked out and overgrown. The line of the tramway once connected with the railway can be seen. Fortunately there is a description of the section in the old pit by Bury [16]. Mr. Calkin has kindly added a photograph and notes made in 1927-8. A drawing made in May, 1927, shows a bed of white clay 6in. thick overlain by unbedded gravel with two lenticles of sand, one cross-bedded. The top of the gravel, under the soil, is contorted. Sharp Acheulean hand-axes were found in and just above the white clay. A continuation into the Sleight terrace-gravel is still open and has now been pushed across the plateau to the eastern bluff. Any working now done is by an entry to the south-east.

The old East End pit, now overgrown and largely built over, is not marked on the map.

Cogdean pit, south of this, is not at the edge of the plateau, but is separated from it by the tributary of the Stour bounding the pit on the east. Though now out of use and partly filled up, it still shows gravel along a front of 200yds. on the line of the depression bounding the plateau to the south; Mr. Calkin has a photograph of the section taken in 1933, just before the pit closed.

At the west end of the depression, the Sleight pit was started in it, but has since been pushed northwards along the terrace-gravel to the northern bluff. It is still open throughout, affording fine sections. At the south end gravel descends in the depression to at least 20ft. below the surface of the Sleight terrace.

The thickness of the gravels in the level part of the Sleight terrace is usually 9-10ft., though it reaches 12ft. where it is now being worked in the Sleight pit at the centre line of the plateau. This terrace-gravel is now well seen near both ends of the plateau, but was not exposed at the time of Bury's investigations. Altogether about 350yds. of face is visible on the level and about the same length on the waxing slope.

Numerous Acheulian implements have been obtained from the Ballast Hole and from Cogdean pit. In both places the level was about 185 O.D. Gravel has, however, been worked in the Ballast Hole from about 170 O.D. and can be seen on the north side of the railway cutting below the Hole. Probably the line of tramway is on the base of the gravels in the bluff.

There is no trace of the Boyn Hill terrace near the Sleight plateau and it is definitely excluded by the Iver terrace on the north-east and west. It is found a mile to the east as the Higher

Merley terrace of White [9, p. 54], sloping from 160–145 O.D. ; and on the opposite (north) side of the Stour it is met a mile and a quarter north of the plateau at about 152 O.D. It extends half a mile farther north.

It would appear that, when this part of the river Stour was in a Boyn Hill stage, it flowed in a broad meander a considerable distance north of Sleight round a spur of the Sleight terrace. The depression south of the plateau marks the site of a streamlet, tributary to the Stour, flowing east in a small valley about 25ft. deep. Cogdean pit is entirely in gravel filling this valley. Mr. Calkin informs the writer that trials south of the road at Cogdean found the gravel too thin to be worth digging. A minor valley would have tended to be choked by the flint gravel of the Sleight terrace and, once it had been beheaded by the tributary of the Stour bounding the plateau on the west, would become nearly filled by soil-creep. Bury noted that in both pits part of the gravels resembled hill-wash.

The presence of the Iver terrace in the valley west of the plateau shows that the streamlet was beheaded during the Iver stage of the Stour. The Cogdean palaeoliths must, therefore, be dated to some part of the Boyn Hill stage.

Remarkable large flints and sarsens found in the Cogdean pit, which is near the base of the bluff to the Ambersham terrace, were probably relics of the Ambersham terrace-gravels, into which they were floated by ice during the Chalky Boulder-clay glaciation.

Lower Thames. A more intricate and important series of sites than those considered above are the pits round Dartford and Swanscombe, which centre round the "100ft. terrace." It is suggested that geomorphological methods may afford some assistance in their interpretation.

The existence of a wide ancient floor in the Lower Thames, about 100ft. above the river, is mentioned by early writers, *e.g.*, by Evans. The first adequate description was by Pocock [17] in 1903. He termed it "the 100ft. terrace" and, after noting that its channel was seven miles broad east of London, wrote :

Throughout the 40 miles from Staines to Grays the upper terrace maintains the same average height above the sea level. Its under surface varies from place to place, but generally speaking it is about the 100-ft. contour line near its margin. Towards the centre of the old channel, as at Brentford and North Ockenden, it descends to a lower level. But no general inclination can be traced as it is followed down the valley towards the sea.

At that time, for reasons not apparent to the writer, the custom was growing in this country of describing terraces by the levels of their gravel bases, instead of by their surface levels. However, taking the usual thickness of the surface deposits, Pocock's description suggests a terrace with a landscape margin towards the river of some 115–120 O.D. In view of the great breadth of the terrace

and its recognised inward slope, it seems moderate to allow a rise of 20ft. to the outer margin, which would then be 135–140 O.D.

In 1905 Hinton and Kennard [18] defined two terraces by the classical system of their surface levels. The higher was styled the First, or Dartford Heath terrace :

This is well seen at Dartford Heath, 136 O.D., and Dartford Brent, 131 O.D. . . . The well-known terrace at Greenhithe and Northfleet, 100ft. O.D. must be considered as belonging to a later stage. . . . After the deposition of the Dartford gravel an elevation of the land occurred, probably to a height of about 30ft., and on the Thames eroding its bed to base-level, the deposition of another sheet of gravel ensued.

The lower terrace is referred to as the Second or Swanscombe or 100ft. terrace. It will be noticed that the Dartford Heath levels fall within the inferred limits of Pocock's 100ft. terrace.

In 1909 the *Geological Survey Memoir* on the London District accepted these views. The terms used were 1st Terrace ; and 2nd (High or Upper) Terrace, generally known as the 100ft. terrace.

In 1912 the *Geological Survey* [19], pointing out the ambiguous character of other nomenclatures, announced their intention of adopting local names :

At Boyn Hill there are an upper and lower terrace, more or less distinct. . . . In other parts of the district the two terraces merge into a continuous slope. The upper Boyn Hill terrace may with some certainty be correlated with the 130-ft., the lower with the 100-ft. of the Lower Thames Valley, but the term Boyn Hill terraces will be used to describe features and deposits which may belong to either or both of these minor divisions.

In the same year Chandler and Leach [20] came to the conclusion that the Dartford Heath gravels were over 40ft. thick and that their base-level was identical with that of the Second Terrace. They inferred that only one terrace was present. This conclusion was strongly supported in the second edition of the *Survey Memoir of the London District* (1922) :

One result of the re-survey has been to indicate the existence of three, and only three, main divisions of the river deposits, and in consequence we can safely speak of the Upper (Boyn Hill or 100-ft.), Middle (Taplow or 50-ft.) and the Low (Flood-plain) Terraces (p. 54).

Dartford Heath is formed by this deposit, which attains the great thickness of 50ft., the base-level being about 88ft. above O.D. (p. 55).

This system had already been adopted in the *Windsor and Chertsey Memoir*, 1915, and later was used in a number of Thames sheets, including Dartford, 1924, which covers Dartford Heath and Swanscombe ; also in the regional *Memoir on London and the Thames Valley*, 1935.

The published evidence for this rejection of the earlier views is twofold. Firstly, continuity of the gravels and slopes. This argument has, however, broken down wherever more detailed measurements have been applied. For instance, the gravels south-west of Southampton Water have been treated as a continuous sheet from 140–30 O.D. for a century ; but the writer has been

able to show that they prolong the terraces west of the Avon. It may be said that the division of the Boyn Hill terraces in the Beaconsfield district is only of minor importance ; but the distinctness of the bluff between two terraces, while dependent partly upon age, is chiefly decided by local circumstances, such as the nature of the solid substratum, the width of the terraces and the extent to which the higher terrace has been cut back by the lower. There is indeed some reason to think that, when the meanders on the lower division of the Boyn Hill terrace swung far into the higher, the lower has been put with the Taplow instead of the Boyn Hill.

Secondly, the identity of base-level, as found at Wansunt, Dartford Heath. The wide expanse of Dartford Heath lies between the Cray and the Darent. A considerable proportion of the western Heath is above 130 O.D. The Cray has eroded a valley, nearly down to sea-level, north-west of the Heath. The Wansunt pits are dug into the side of this valley at a point where it is joined by the valley of a minor tributary of the Cray. The gravels which have been described in them obviously include much bluff deposit, channelled in the way characteristic of bluffs ; and the writer has not been able to find any published evidence of the presence in them of any Dartford Heath terrace-gravel *in situ*. Its existence in the bluff can hardly be assumed, any more than the existence of the highest terrace-gravel could be assumed in Broom pit (Fig. 8) ; and a floor uncovered at Wansunt might belong to a lower terrace or to an episode in the construction of the river-cliffs once bounding the Cray valley.

The first sign of doubt in the triple classification appeared in 1934, when, in a Weald Research Committee paper on the river Mole, E. A. Turner described a flat at Cobham Park and other areas at 100 O.D., as separate from the Boyn Hill terrace at 140–120 O.D. [21, p. 48]. In the same paper (p. 61) Bull and Wooldridge noted evidence in the profile for this stage. Meanwhile the writer had been mapping terraces in the south of England and in 1936 [22] he referred to corresponding terraces in the Hampshire Avon, Dorset Stour and Frome, and the Devon Otter and Dart. It was termed “Upper Taplow,” since it appeared as part of the Taplow terrace in the Chertsey map, and also in the North London map.

Simultaneously Lacaille and Oakley [23] separated a terrace at Iver, Bucks., which appeared to be equivalent to part of the Taplow terrace. This is evidently the same as the Upper Taplow terrace.

In 1946 the results of the writer's measurements in the Bournemouth area showed that two longitudinally horizontal terraces could be followed from Bournemouth to Southampton Water, a distance of over 20 miles ; one sloping from 140–115 O.D. ; the other from a little over 100–90 O.D. [1]. The higher resembles Pocock's 100ft. terrace and the Dartford Heath terrace ; the lower

corresponds in all respects to the Second terrace of the 1909 *London Memoir* and the Swanscombe terrace of Hinton and Kennard, named by both the 100ft. terrace. Reasons were given for believing that two equivalent high terraces occurred near Swanscombe and Grays.

There is at least a case for some reconsideration of the authoritative classification of the terraces of the Lower Thames and for re-examination of those between Staines and Grays that have been, or should be, assigned to a 100ft. terrace. If there turn out to be two such terraces of importance, the question will arise whether, in view of the occasional ambiguity of the name "Boyn Hill," the prior nomenclature of Hinton and Kennard is not preferable.

On the assumption that there are two such, namely: (1) the Dartford Heath, Boyn Hill or 130ft. terrace and (2) the Swanscombe, Upper Taplow, Iver or 100ft. terrace, deposition of the gravels of the famous Barnfield pit would have taken place somewhat on the following lines.

During the Sleight-Boyn Hill interval a gorge was eroded to below 70 O.D., perhaps to 64 O.D. [24]. While the sea was at its lowest, the Lower Gravels were laid down, followed by the Lower Loam. The resemblance of this primary filling of the Swanscombe gorge to the primary filling of the more recent drowned gorges of the Cornish rivers is noticeable, for example, at Restronguet Creek, near Falmouth [25]. In both a coarse bouldery gravel rests on the solid rock and is covered by fine material with an old soil. In both mammalian bones are not infrequent.

The Lower Middle Gravels were laid down during the rise of the sea to the Boyn Hill (Dartford Heath) level, but before it reached the level of the Lower Loam; probably as aggradation in the rear of a growing delta. During the Boyn Hill (Dartford Heath) standstill, a wide floodplain, veneered with gravel, was formed, with surface ranging roughly from 140-120 O.D. It is not represented at Barnfield pit.

In the Boyn Hill-Iver interval the gorge was partly re-excavated and the buried channel gravels laid down. So far the Barnfield deposits may be regarded as parts of the foundations of bay deltas.

During the Iver (Swanscombe) standstill the Thames cut laterally out of or into the gorge, destroying much of its northern bank and depositing terrace-gravel, the Upper Middle Gravel. A Boyn Hill-Iver bluff was initiated.

Everything above the Upper Middle Gravel consists of bluff deposits, comprising the solifluction raft of sand, the Upper Loam, the sludged Upper Gravel and the final wash.

Gratitude is due to Mr. J. B. Calkin, whose knowledge of the gravels round Bournemouth has afforded valuable aid. Copies of his photographs are being placed in the Association's collection.

Mr. A. S. Kennard's advice and criticism has been very helpful, especially in connection with the Lower Thames.

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THE DEVELOPMENT OF A BRITISH APTIAN BRACHIOPOD

By GRAHAM F. ELLIOTT, F.G.S.

INTRODUCTORY AND SYNONYMY

ONE of the most important advances in our knowledge of the brachiopods was when it was shown that in the Recent terebrateloid or long-looped brachiopods brachial structures, which are similar when adult, attain their final form in different genera by different series of metamorphoses or growth-stages, and that these immature growth-stages often correspond in plan if not in size and proportion to the adult loops of other genera. These observations, first summarised and developed as a basis for classification over half a century ago (Beecher, 1893) have formed the basis of much subsequent taxonomic work, although most other brachiopod characters have now been brought into use for this purpose. Owing to the relative scarcity of Recent brachiopods, and to the infrequency with which good series of immature examples of these creatures are dredged, only about seven complete developmental series have been described and figured, a state of affairs unremedied by zoologists and Tertiary palaeontologists who prefer to multiply generic and specific names rather than devote their energies to the understanding as living organisms of forms already described. As regards fossil forms, the position is much worse, for although so much more numerous than their Recent descendants, it is only exceptionally that the vagaries of preservation permit dissection of small immature forms, and the variety of the faunas itself casts doubt on the correct attribution of such little specimens to a species. Curiously enough, the earliest study of the development of a long-looped brachiopod was made on an English Jurassic species (Moore, 1860), 17 years before the classic paper on the development of the North Atlantic terebrateloids (Friele, 1877), but the time was too early for full appreciation of the significance of the facts recorded. It is hoped, therefore, that the present study of development of a Lower Cretaceous terebrateloid, a form considerably earlier than the Tertiary faunas which link on to the Recent, and yet itself still showing close structural parallels to living forms, will be of sufficient interest to encourage the collection of immature brachiopods, Recent and fossil, when these are available.

The brachiopod discussed here is familiar in the literature of the British Aptian as *Terebratella menardi*, and was first described and figured, from the Faringdon Greensand, by J. de C. Sowerby in 1826 as *Terebratula truncata*. In this application the name was a homonym, for Linnaeus's *Anomia truncata* (the recent Mediterranean

Mühlfeldtia truncata) had already been referred to *Terebratula* by various authors subsequent to Lamarck's restriction of the genus *Anomia* to certain lamellibranchs (Lamarck, 1801). D'Orbigny later referred the Mediterranean brachiopod to his genus *Terebratella* (d'Orbigny, 1847) and in 1850 did the same for the Aptian species. King's transfer of the Recent *truncata* to his genus *Megerlia*, also published in 1850, was subsequent to d'Orbigny, and does not affect the synonymy.¹ Recognising the duplication, d'Orbigny proposed (d'Orbigny, 1850) to give Sowerby's species the trivial name *asteriana*, but the description and figures he gave at the same time refer to a different species from the French Aptian. In the collections of the British Museum (Nat. Hist.), dept. Geol., topotype examples of *T. asteriana* from two of d'Orbigny's localities are preserved (Reg. Nos. B. 6688-89) and a MS. note of Davidson's attached to the back of the tablet records that one specimen was sent to him by d'Orbigny himself. These fossils are clearly distinct from Sowerby's *truncata* (for comparisons see below under "Discussion and Affinities"). Davidson in 1852 referred the latter to the Cenomanian *Terebratella menardi* (Lamarck) from which it is likewise distinct, though perhaps related. In 1874, in his revision of the Cretaceous Brachiopoda, Davidson lists *truncata* rather grudgingly as "this species, or variety of *T. menardi*." Since *T. menardi* and *T. asteriana* refer correctly to species other than the one under consideration here, and one cannot return to the use of the rejected homonym *truncata*, a new trivial name is here proposed and on grounds of development and structure it is referred to a new genus also.

Superfamily	...	<i>Terebratellacea</i>	Allan, 1940
Family	...	<i>Dallinidae</i>	Allan, 1940
Subfamily	...	<i>Gemmarculinae</i>	nov.

Primitive Dallinidae with stout internal structures and latero-posterior flanges present on the brachial structures at all growth-stages. Cretaceous.

Gemmarcula gen. nov.

(Reference is to the delicate internal structures often present within the shells)

Biconvex, transverse, striated, dallinid terebratelloids, with stout internal structures, and an early form of dallinid loop-development. Species: *G. aurea* sp. nov. (the genotype), *G.*

¹ *Megerlia* with genotype *Anomia truncata* Linné (ascribed to Gmelin), pp. 81, 145 in King, W., Mon. Perm. Foss. England, *Mon. Pal. Soc.*, being part of vol. iii for 1849, issued Aug., 1850. D'Orbigny's 1850 reference to *T. truncata* J. de C. Sow occurs in his *Pal. Franç., Terr. Crét.*, iv, livr. 145, pp. 116-17. The date of livraisons 145-152, pp. 105-200, which includes the above, is given as 1850 (Sherborne 1899). In *Bull. Soc. Géol. France* (2), vii, p. 289, in the report of the Society's meeting on the 4th March, 1850, there occurs in a list of books presented to the Society the following: "M. Alcide d'Orbigny, *Pal. Franç. . . . Terr. Crét.*, livr. 127-150." Thus the relevant 1850 reference of d'Orbigny precedes that of King by about five months.

menardi (Lamarck) ; positive attribution of this latter to the genus is dependent on a study of internal structure and loop-development.

Gemmarcula aurea sp. nov.

(Reference is to the bright yellow iron-staining
of topotype specimens)

1826. *Terebratulula truncata* : J. de C. Sowerby (non Linné), Min. Conch., vi, p. 71, pl. 537, fig. 3.

1850. *Terebratella asteriana* : A. d'Orbigny (partim), Pal. Franç., Terr. Crét., iv, pp. 116-17, pl. 516, figs. 6-12.

1852. *Terebratella menardi* (Lamarck) : T. Davidson, Mon. Brit. Foss. Brach., i, pt. 2, pp. 24-26, pl. 3, figs. 34-39, 41.

1874. *Terebratella truncata* (Sow.) : T. Davidson, Mon. Brit. Foss. Brach., iv (Suppl.), pt. 1, p. 25.

DIAGNOSIS

Shell about 13mm. long, 13mm. wide and 7mm. thick ; biconvex, ovatequadrilateral, coarsely striate, anterior commissure parasulcate. Umbo short, sub-erect, markedly truncated ; foramen large, vertically ovate, sub-mesothyrud ; prominent symphytium, area high, hinge-line sub-megathyrud. Stout hinge-teeth, dental lamellae and pedicle-collar : strong median internal ridge in pedicle-valve. Cardinalia strong, buttressed by median septum and crural bases, cardinal process transverse and countersunk, inner and outer socket-ridges present. Loop primitive terebrataliform.

Holotype

The specimen figured in Plate 3, figs. 8-10, British Museum BB. 9251, from the Aptian Sponge Gravel of Faringdon, Berks.

Paratypes

BB. 9246-50, 9252-65, all from the same locality and horizon.

DESCRIPTION

A high percentage of the Faringdon brachiopods are immature ; study of a shallow-water colony of the Recent *Terebratella inconspicua* (Sowerby) (Percival, 1945, p. 4) showed a numerical preponderance of young forms : this author concludes that some die owing to lack of room for growth, and he continues : " It seems that very many young ones become thinned out in the first year, in part through overcrowding, in part through starvation, and in part for no apparent reason." Loss of the weak early attachment may account for this latter category. However, the phenomenon as a whole permits the study of the development of various structures in detail.

In the account following the descriptions of external morphology, and of internal structures other than those of the loops,

are based on good series of specimens for each stage, with the exception of the smallest specimen (Fig. 1), which was unique. As regards the loops, at least one perfect specimen and three or four broken ones were dissected for each stage, making a total of about six in each case, the unique smallest loop (Figs. 19, 20) again excepted. The terminology adopted is mostly to be found in Thomson (1927).

External

The smallest specimen examined (Fig. 1) has a width of 0.7mm. At this early stage the pedicle-opening (po) is a wide triangular gape with rounded apex, flanked either side by a narrow incipient interarea (i) and the thickened edge of the pedicle valve (e) : the latter feature exceeds the interarea in width. At 1mm. shell-width (Fig. 2) the interareas are much more prominent, and might be mistaken for deltidial plates, but these do not appear until 2mm. shell-width (Fig. 3) when they form narrow strips (dp) within the interareas and afterwards grow first into the usual triangular plates and ultimately fuse into a symphytium (sy), thus converting the triangular pedicle-opening into the mature oval foramen (f). The degree of development of the circumforamenal structures for a given size of shell varies considerably and some individuals were much more forward than others in this respect. Thus in two specimens, both of 5mm. shell-width, the deltidial plates differ from two narrow strips in the one case to two triangular plates, their inner edges curved owing to abrasion by the pedicle, in the other. Again, in different individuals both of 7mm. shell-width, disjunct deltidial plates and a symphytium are found. In this species the hinge-line only rarely becomes more curved than sub-megathyrid, the area remains wide and prominent, and even in fully adult shells faint grooves delimit the three successive pairs of circumforamenal structures. Abrasion usually removes the apex of the pedicle valve at an early stage (e.g., at 3mm. shell-width) and the whole area or palintrope slopes back at an angle up to 60° from the plane of separation of the valves ; in old age, anterior shell-deposition at the valve-margins may greatly diminish this angle.

The specimen shown in Fig. 15 is one of two, interesting as having by chance escaped this normal abrasion of the beak (x) which occasioned Sowerby's trivial name of *truncata*, and in consequence they are in outline reminiscent of some Palaeozoic brachiopods. Living species with large foramen and long hinge-line, such as *Mühlfeldtia truncata* (Linn.) or *Terebratalia transversa* (Sow.) (Fig. 5) are attached by very short stout pedicles to stones or other solid objects on the sea-floor, and gradual increase in shell-size during growth incurves the umbo with consequent abrasion. The two Aptian brachiopods must have been attached to the very

edge or corner of a sponge or stone to preserve the beak, a precarious position in a current, which doubtless explains their rarity and small size. If a whole colony had developed in this fashion, they would no doubt have merited (and long since received) a separate trivial name.

In the tiny specimen of 0.7mm. hinge-width the valves are smooth except at the edges where seven feeble incipient costae are seen on each valve, alternating at the anterior commissure, which is itself rectimarginate. Throughout successive growth-stages these little costae augment into coarse sharply rounded *striae*, the terms *plicae* and *sulci* being here reserved for major folding of the valves affecting both outer and inner surfaces, and the term *striae* being chosen in preference to the analogous, but finer capillae characteristic of the genus *Terebratulina*. Nine striae are seen at 2mm. shell-width, 12 at 4.5mm., 22 at 7mm., and 30 at 9mm.; there is considerable individual variation in this respect. The new striae appear both by intercalation and by bifurcation, and also in a manner not strictly to be referred to either of these, incipient striae developing as slight features on the side-slopes of existing ones and then diverging. The striae are regularly radial, the central ones being straight and the lateral ones curving gracefully to left and right; numerous lines of interruption of growth cross them at irregular intervals, and when these are close-set they give the appearance of the ridge-tiles on a house-roof.

Although the striae alternate at the anterior commissure, this is itself in general trend rectimarginate at first. The central striae of one valve, however, become steeper and new striae develop on the slopes, the other valve opposing throughout; in this way a brachial-valve plica margined by two sulci arises, opposed by a pedicle-valve sulcus margined by two plicae, and the commissure becomes parasulcate (Fig. 8) without passing through the intermediate uniplicate stage described in the literature of smooth terebratuloids (Buckman, 1918; Thomson, 1927, p. 58). Incipient parasulcation is seen at 5mm. shell-width, and it is clearly marked at 7mm.; it varies in different individuals from wide and shallow to narrow and high. In outline, the shell is transverse in most individuals at all growth-stages: in old age, however, a fair number become more elongate and when this is combined with sharp folding the shell may project anteriorly. A minority of specimens trend towards plano-convexity. Asymmetrical specimens occur not uncommonly: in examples examined of the Recent *Terebratalia transversa* (Sow.) from a stony bottom in Puget Sound, U.S.A., asymmetry was external only, the loop being smaller but central and normal in form. Figures of specimens of *Terebratella dorsata* (Gmelin) from Cape Horn (Fischer and Oehlert, 1892) show, however, asymmetry also ascribed to the influence of solid bodies on the sea-floor which affected the loop also. The Faringdon

specimen shown in Fig. 6, although water-worn, would have come in this second category, judging by the displacement of the median septum.

Internal

(a) Pedicle¹ valve (Figs. 4, 13, 16, 17, 18). In the interior of this valve a thick pedicle-collar (pc) lines the umbo, cemented at the sides to the dental lamellae (dl) and passing dorsally into the symphytium. The dental lamellae are thick, converging slightly both posteriorly and upwards, and buttressing the hinge-teeth (te). On the inside of the symphytium is a calcareous deposit, thickening anteriorly, irregularly developed and occasionally anteriorly divergent; this is here designated the symphytial wedge (sw). The three structures formed a solid sheath for the pedicle, and the pedicle collar and dental lamellae appear in ontogeny as early as a shell-width of 2.5mm., before the coalescence of the deltidial plates into a symphytium.

In the main portion of the valve the most conspicuous feature is a prominent broad rounded ridge (mf), corresponding to the external median sulcus, arched over by the internal calcareous deposit, and extending and widening from the pedicle-collar anteriorly. It varies in development as the external parasulcation varies, and in most specimens commences immediately in front of and against the pedicle-collar; in some specimens, however, this projects freely over the median ridge for a short distance and in one case a solid deposit of callus unites pedicle-collar, posterior median ridge and shell-floor. Elsewhere, all features are obliterated except for the crenulated valve-margin, corresponding to the external striae, and muscle-impressions, only seen clearly in large gerontic specimens. These consist of an inner narrow elongate pair (ims), immediately left and right of the median ridge, and an outer wider pair (oms), of which the anterior margin sometimes corresponds with the position of an external line of interruption of growth, but the effect of other external features is obliterated internally. Adductor, diductor and adjustor muscles would all have been attached in the area under consideration, and their separate scars are not preserved.

(b) Brachial valve. In the young brachiopod the most conspicuous internal features are the two articulatory sockets (hs), separated by a simple hinge-platform, plane or slightly concave, which falls steeply anteriorly to the floor of the valve. After the hinge-platform becomes fully buttressed by the median septum (s) (of which the development is described below with that of the brachial structures) it becomes much more massive, and a number

¹ It has been shown recently (Percival, 1945, pp. 10, 16-17) that in the living terebratulid *T. inconspicua* (Sowerby) considerations of embryology and anatomy indicate that the larger valve is dorsal and the smaller ventral, the reverse of the conventional view. It seems better to accept this author's recommendation to use the terms "pedicle" and "brachial" in palaeontology and conchology.

of separate structures are discernible, becoming clearest in fully adult individuals, on which the following account is based.

Both outer and inner socket-ridges (osr, isr) are present : the outer ones lie immediately within the margin of the valve, meeting this just short of the umbo. The inner socket-ridges begin laterally then rise sharply on the inner sides of the sockets, curving round and merging with a flange or ledge (hfl) bordering the cardinal platform. This is buttressed anteriorly by the median septum and joined to left and right of this, a little higher, by the crural bases (cb). Two prominent bosses (p) occur left and right on top of the cardinal platform ; they curve posteriorly, with a slightly concave surface between, which is posteriorly striated (st). The effect is that of a prominent cardinal process, such as characterises the austral Terebratulidae, countersunk in or fused with the cardinal platform ; it is suggested that this may be the manner in which the inconspicuous cardinal processes of the Dallinidae originated.

Internal shell-deposition obscures all other features on the floor of the valve except for a crenulated margin similar to that of the ventral valve. Neither on free valves nor on artificially prepared moulds have clear muscle-scars been observed, though presumably they occupied the posterior third of the valve on either side of the septum.

(c) Brachial supports, or loop. The earliest stage of loop-development observed in *Gemmarcula aurea* is in a specimen of 2.5mm. shell-width (Figs. 19, 20). A short stout septal pillar (sp), quadrangular in side view and inclined forwards, rises in the centre of the valve. The upper portion of the pillar is grooved (g), with an anterior divergence of the two sides ; posteriorly the groove is roofed over by a wide flange (fl) extending to left and right, of which the plane points downwards to the foot of the cardinal platform. The extremities of the flange are down-curved ; the covered groove or perforation (pf) emerges posteriorly. Two descending branches (db) curve outwards from the crura, and fringed with a few short scattered spines, are attached to the septal pillar left and right, separately from the top structures. This constitutes the *early pre-campagiform* stage (see below under " Terminology of Loop-development ").

The later pre-campagiform stage is seen in a shell 3.5mm. wide (Fig. 22, 23). The median septum now commences as a low ridge at the foot of the cardinalia, rising anteriorly to the septal pillar. The descending branches run obliquely up the sides of the pillar to the anterior divergence, more developed than previously and now spinous. The perforation has become wider and shows anteriorly as a low equilateral triangle, the apex pointing downwards and the base being the underside of the flange, which still slopes as before, and has a double keel on each extremity. In the specimen examined the descending branches are not spinous, though this

character reappears in the next growth-stage ; no doubt spinosity varied individually to a certain extent. It has been suggested (Woodward, 1854) that loop-spines, *e.g.*, in *Ismenia pectunculoides* (Schloth.), represented calcareous supports for the cirri of the lophophore. Possibly the finely and densely-cirrated lophophore of Recent forms is a relatively modern development.

The *campagiform* stage is seen in specimens of 4-5mm. shell-width (Figs. 25, 26, 28, 29). The median septum now commences by buttressing the foot of the cardinal platform, sinking a little and then rising steeply to terminate at about three-fifths the length of the valve. The descending branches, spinous, broaden their basis of attachment to the septum to extend across the diagonal length of the higher portion, and they terminate anteriorly by recurving into the lower divergent sides of the hood (h), fringed with spines. This hood is the successor of the earlier rounded-triangular structure ; it becomes larger and more rounded, more open at both ends, and the spinous anterior lamellae diverge and curve back to the descending branches. The flange no longer projects laterally, but is converted into an upward and backward extension each side, the double keels becoming separate parts of this extension, whilst a rounded notch posteriorly reduces the relative width of the hood, which thus becomes recognisable as an early form of the adult transverse band. Anteriorly the effect is that of a cowl-like head with two ears.

The *frenuliniform* stage occurs at 6mm. shell-width (Figs. 31, 32, 33). The median septum now buttresses the cardinalia strongly, curving gently downwards, then upwards anteriorly to the point of attachment of the ascending branches of the loop, after which it sinks rapidly to the shell-floor at about three-fifths the length of the valve. Enlargement brings a progressive smoothness to the loop so that its component structures merge gracefully into one another and are proportionally slighter, and spinosity disappears, except where the ascending and descending branches curve into one another, anterior of the septum. The attachments of the descending branches (cbd) to this are still broad, passing upwards and outwards into the sides or early ascending branches (ab) which support the transverse band (tb) with its distinctive and prominent postero-ventral "ears" (au). In these broad sides, however, resorption produces lacunae or ovoid gaps (l) so that two pairs of connections between the upper and lower structures are individualised.

The *terebrataliform* stage (Figs. 21, 24, 27) occurs in shells of 7mm. width and over, and is attained by the resorption of the posterior pair of supports present in the frenuliniform stage, so that the loop is of a familiar pattern ; the descending branches after leaving the crura (c) being attached once to the median septum, then recurving upwards into ascending branches which pass into the transverse band. This still bears its distinctive ears. In the early terebrataliform stage figured (7mm. shell-diameter) there is still a

certain angularity about the curves of the loop : larger specimens with unbroken loop have not been dissected, but there is little doubt that, as in Recent forms, the loop becomes progressively more delicate and spindly with increase in size ; this is even noticeable in the lower portion of a broken loop of a specimen of only 8mm. shell-width. The septum functions mostly as a buttress to the cardinalia, and becomes proportionally lower in its extension anteriorly to the loop-connections. There is no evidence that *G. aurea* ever attained a *dalliniform* loop, since traces of the connections have been found on all undamaged median septa examined. The present writer, however, has seen occasional gerontic individuals of the Recent austral terebratellids *Magadina cumingi* (Davidson) and *Terebratella sanguinea* (Leach), which attained loop-stages one later than those characteristic of their species ; *i.e.*, from magelliform to terebratelliform and from terebratelliform to magellaniform respectively, so a dalliniform *Gemmarcula* is not an impossibility.

TERMINOLOGY OF LOOP-DEVELOPMENT

The stage of dallinid loop-development before the frenuliform stage is attained was referred to as ismeniform (Beecher, 1893), to which the term pre-ismeniform was later added for the earlier stage (Thomson, 1927, p. 232). Beecher compared the former with the figures of *Ismenia furcata* (Sow.) and *Ismenia buckmani* (Moore) from the English Bathonian, referred to *Terebratella* (Moore, 1860) and now to Rollier's genus *Hamptonina* (genotype *T. buckmani* Moore ; Rollier, 1919). *Ismenia* King has, however, for genotype *Terebratula pectunculoides* Schlotheim (King, 1850) from the Upper Jurassic of Germany, of which the loop as figured (Davidson, 1850 ; Quenstedt, 1852) is certainly not " ismeniform," and a study of its loop-development is necessary before *H. furcata* and *buckmani* can be referred to the genus. Thus comparison of the so-called ismeniform stage of Recent brachiopods is not really with *Ismenia*, but with *Hamptonina*, and as stated below (see under " Discussion and Affinities ") the development of *H. buckmani* as described and figured renders it very doubtful if this form is a true terebratelloid. Since comparison of the frenuliform, terebrataliform and dalliniform immature stages of Recent dallinidae is with genera showing these patterns of brachial structure when adult, the same should be done for the earlier stages hitherto known as ismeniform and pre-ismeniform. Of the three eligible genera listed by Thomson (Thomson, 1927, p. 239), *Jolonica* Dall has not been figured and the description is not clear, and *Jaffaia* Thomson has recently been transferred to the Terebratellidae (Allen, 1940). The third, *Campages* Hedley is not an exact adult homologue of an " ismeniform " stage, since ascending and descending branches have grown forwards into a funnel or hood, but it is a " modified

ismeniform" and so to avoid further confusion the terms *pre-campagiform* and *campagiform* are here introduced to replace *preismeniform* and *ismeniform*.

DISCUSSION AND AFFINITIES

In most recent long-looped brachiopods the shelly brachial structures supporting the fleshy lophophore pass through varied different developmental stages, arriving in the higher forms at homologous adult structures reached by different developmental paths. Adequate correlation of the intermediate growth-stages of lophophore and loop, of animal and shell, has not yet been made, though isolated examples are on record (Beecher, 1893, pl. II, Figs. 4-5; 1897); all that is known is that with the increase in length of the cirrated lophophore-margin, the cilia of which produce the water-currents providing for food and oxygenation, two doubled side-arms develop early, and a median coil later. Hence the early appearance of lateral descending branches, and the curious phenomena leading to the transverse band of the loop supporting the median coil. It remains doubtful whether the loop-changes are purely palingenetic, or functional, or both, and so it is impossible to assign full biological value to the phenomena discussed below.

When comparison is made of the loop-development of *Gemmarcula aurea* with similar studies on other forms, its affinities are quickly revealed; it agrees with the Recent Dalliniinae *Waldheimiathyris cranium* (Muller), *Dallina septigera* (Lovèn), *Dallinella obsoleta* (Beecher) and *Frenulina sanguinolenta* (Gmelin), species of genera typically distributed in the northern hemisphere. It differs from *Terebratella dorsata* (Gmelin) and *Terebratella inconspicua* (Sow.) which belong to a rich assemblage of forms from the southern hemisphere, placed as Magellaninae by Thomson and since further subdivided (Allan, 1940). The two examples given pass through a different series of immature stages to those of the Dallinidae, to reach a final form not unlike that of the northern forms. The development of *Gemmarcula aurea* is also distinct from that of the Mediterranean *Mühlfeldtia truncata* (Linn.), which differs from both the northern and southern forms cited. The other form with which comparison may be made is *Hamptonina buckmani* (Moore), which passes through stages of development of ascending and descending branches (Moore, 1860, Pl. XIII, Figs. 1-4), which bring it to an apparent campagiform stage. But Moore distinctly states (pp. 441-42) that the median plate (septum) does not reach the floor of the valve till the last (campagiform) stage; i.e., the earlier developmental stages take place free of the floor of the valve. The other observations of this careful worker are detailed: pending a re-examination of this species, it seems most advisable to accept his description, and to conclude that *Hamptonina* is a Zeillerid genus (very little is known of the development

of the zeilleridae) and not a terebrateloid¹: a view indirectly supported by the geological age of the genus. A dissected specimen of *H. buckmani* examined by the writer was broken, but showed a low median septum of the usual type with descending branches: this does not invalidate Moore's description of the earlier stages.

Gemmarcula aurea, then, is seen to be a form of dallinid type. Careful comparison with Recent dallinids, however, reveals certain differences. The cardinalia, dental lamellae, septum and ribbons of the loop are stout, a feature which is primitive compared with the thin well-placed structures of the higher members of the family. (See also Thomson, 1927, pp. 83-84.) In addition, all known growth-stages of the loop possess the curious postero-lateral flanges, though the general pattern of development attains to the terebrataliform or penultimate stage of more familiar forms. If the adult flanges were continued backwards to fuse with the median septum, the resulting loop would be somewhat similar to that of the Cretaceous genus *Kingena* as figured (Davidson, 1852), which has always been interpreted as an early dallinid. The only present-day features at all reminiscent of a gemmarculid loop-structure are the two small lateral projections described (Beecher, 1893, pp. 393-94, Pl. III, Figs. 3-6, 8) on the early septum of *Dallinella obsoleta* before the growth of ascending and descending branches: it is here suggested that they may be palinogenetic, even though the morphology of the loop-development of *Gemmarcula aurea* compares most closely with that of *Waldheimiathyris cranium* (Muller). For these reasons, the genus *Gemmarcula* is placed in a separate subfamily to the Dallininae and Laqueinae, and it is hoped that other investigations of European Cretaceous Dallinidae will further extend our knowledge of the family, which is no doubt capable of subdivision in the same fashion as in the Terebratellidae (Allen, 1940).

Of the other Cretaceous species with which *G. aurea* has been confused, *Terebratella asteriana* d'Orb. from the French Aptian differs in being more elongate, not truncate, and in possessing finer ornament and a much less strongly folded anterior commissure. The Cenomanian *G. menardi* (Lam.) is a wider form, with clearer-cut striae more acute than in the Faringdon species: the cardinalia appear similar through the adult septum is much more reduced.

The British Aptian *Terebratella oblonga* (J. de C. Sow.) possesses a completely different type of cardinalia and folding: the Cenomanian *T. pectita* (Sow.) also has different cardinalia, whilst specimens examined of *T. trifida* Meyer, *T. fittoni* Meyer and *T. davidsoni* Walker do not suggest close relationship to *G. aurea*.

¹ If the loops of the zeilleridae do not in ontogeny develop both from the cardinalia and septum, their grouping as a family of the Terebratellacea (Allen, 1940) may need emendation.

NOTE ON THE CONDITIONS UNDER WHICH THE FARINGDON SPONGE-GRAVEL WAS FORMED

The richness and fine preservation of the Faringdon fauna has usually been taken to indicate the fossilisation *in situ* of a bank of calcisponges with the attached and perhaps commensal assemblage of smaller organisms, the whole forming an ecological assemblage similar to that of a coral reef, and possibly owing its origin to the sponge-anchorage afforded by the Palaeozoic and other pebbles found in the deposit. On the other hand G. M. Davies concludes that the coarser constituents, contemporaneous and derived, of the gravel were concentrated in a channel on the sea-floor by currents (Davies, 1939) a view supported by the occurrence of well-rounded pebbles of foreign materials and strongly waterworn fossils, both indigenous and remanié, throughout the vertical extent of the gravels. In this connection the evidence from the material handled in the present investigation is of interest; 84 per cent of about 500 specimens were worn disconnected valves, often well-rounded pieces: the remaining 16 per cent had both valves in position, and usually showed the finest details of ornament and circumforamenal structures; when opened, they often displayed the incredibly delicate immature brachial structures already discussed. It is certain that such specimens were buried quietly, and virtually in the position of growth: it is equally certain that the other specimens had been well and truly rolled and water-worn, a conclusion which receives additional justification from the fact that terebratuloid brachiopods in contracting the muscles at death pull the valves tightly together, and are buried in a bivalved condition, in all but turbulent marine environments, whereas the reverse case is true of most non-burrowing lamellibranch mollusca, which usually occur fossil as single valves. The explanation of this anomaly appears to be that the sponges, taking advantage of an irregularity in the sea-floor, grew in shallow rapidly moving waters. Pebbles and worn remanié fossils were swept amongst them by the currents, and dead sponges themselves were battered and rounded until drifted into a position of rest. The brachiopods, and other attached organisms, lived in crevices and cavities of the sponge-bank: those unfortunate enough to lose their anchorage were whirled away with other detritus by the currents, the remainder lived and were buried where they grew. In sifting material in the pit, almost every sieve-full yielded water-worn material; bivalved individuals were rarer, but occurred in threes and fours, a fact consonant with the known gregarious habits of these creatures, where three or four young settle on or adjacent to their parent. Some adult Faringdon specimens are gibbous variants of the normal transverse forms: a parallel condition described in a Recent wide-hinged form identified as "*Terebratalia obsoleta* Sowerby" (du Bois, 1916) from Puget Sound, was stated to occur in individuals

from shallow disturbed waters, or current-swept areas. The structures of the beak and large foramen of the Faringdon species indicate a strong functional pedicle throughout life, necessitated by the current in which these brachiopods lived; the variation observed is evidence of the constricted environment often consequent on a firm anchorage.

TECHNICAL NOTES

The Faringdon brachiopod fauna is composed of several distinct species, and immature individuals of all of these occur. For the present study, all the specimens were taken from one horizon; the yellow sand immediately below the hard indurated seam exposed at the foot of the north face in the large pit at Little Coxwell, and all were taken within a few yards laterally. The hard seam above appears to have protected this basal sand from percolating water and the fossil contents are better preserved as biological material than those from elsewhere in the sponge gravel beds. The young *Gemmarcula aurea* are easily distinguished from rhynchonellids and terebratulids of the same size: the only two forms with which confusion is possible are *Terebratella oblonga* (J. de C. Sow.) and *Megathyris* sp.; the former differs in its elongate outline and recti-marginate commissure, the latter by its "opposite" folding and distinctively coarse well-spaced punctae: moreover, in several hundred brachiopods collected, only one doubtful example of each of these was found.

The dissection of internal structures for this work was carried out by the usual technique of cleaning the fossil under water with camels-hair brush and mounted needle, but a hypodermic syringe fitted with a fine needle was very useful for directing fine currents of water through the foramen and thus "softening up" the interior before the valves were separated.

ACKNOWLEDGMENTS

I am much indebted to Maj. Royde, of Little Coxwell Lodge, near Faringdon, for affording me every facility to collect from the pit situated on his property, and for his kind interest in the work in progress; to Messrs. A. G. Davis and T. F. Grimsdale, who collected with me and to whom I am indebted for some fine specimens; to Mr. R. Melville (Geol. Surv.) for his generous permission to publish my conclusions on the formation of the sponge-gravel in advance of the publication of the study of the whole deposit he has long had in hand; to Prof. S. W. Muller, of Stanford University, who kindly sent me some Recent brachiopods for comparison purposes, and to Mr. W. N. Edwards, Keeper of the Dept. Geology, British Museum (Natural History) and to Dr. H. M. Muir-Wood, for permission to examine specimens in the collections in their charge.

EXPLANATION OF PLATES 3 AND 4

All specimens figured are now in the collections of the British Museum (Natural History), Dept. of Geology, except that in Fig. 1, unfortunately lost. All of *Gemmarcula aurea* from the Yellow Sponge-gravel (Aptian) of Little Coxwell Pit, Faringdon, Berks., G. F. Elliott Coll., except No. 5.

1. 0.7mm. stage : x 30.
2. 1.0mm. stage : x 20. Brit. Mus. Reg. No. BB. 9246.
3. 2.0mm. stage : x 10. BB. 9247.
4. Asymmetrical pedicle valve, 4.5mm. width, x 4. BB. 9248.
5. *Terebratalia transversa* (Sow.), Recent, 25–50 fathoms, Puget Sound, Pacific coast of U.S.A. ZB. 218, nat. size. The pedicle is so short that the stone has cut into the beak.
6. Asymmetrical brachial valve, 13mm. width, x 2. BB. 9249. Marked internal asymmetry.
7. Brachial valve showing position of adult attachments of loop to septum, 9.5mm. width, x 3. BB. 9250.
- 8–10. Three views of the holotype, 12mm. width, x 2. BB. 9251.
- 11, 12. Two views of a brachial valve to show details of hinge-structures, 12mm. width, x 2. BB. 9252.
13. Internal features of a pedicle-valve, 12.5mm. width, x 2. BB. 9253.
- 14, 15. Two views of a specimen with unworn beak, 5mm. width, x 5. BB. 9254.
- 16, 17. Antero-oblique views of two pedicle valves to show hinge-structures, etc., both 12mm. width, x 2. BB. 9255–56.
18. Interior of young pedicle-valve, 2.5mm. width, x 8. BB. 9257.
- 19, 20. Two views of early pre-campagiform loop, shell 2.5mm. width, x 12. BB. 9258.
21. Early terebrataliform loop, shell 7mm. width, x 4.5. BB. 9259.
- 22, 23. Two views of late pre-campagiform loop, shell 3.5mm width, x 8.5 and x 12 approx. respectively. BB. 9260.
24. Another view of BB. 9259, figured in No. 21 above, same magnification.
- 25, 26. Two views of early campagiform loop, shell 4mm. width, x 7. BB. 9261.
27. Terebrataliform loop, ascending branches broken away, shell 7.5mm. width, x 4. BB. 9262.
- 28, 29. Two views of late campagiform loop, shell 5mm. width x 5.5. BB. 9263.
30. Side view of shell of 4mm. width, to show median septum with attachments of broken loop-structures, x 8. BB. 9264.
- 31–33. Three views of frenuliniform loop, shell 6mm. width, x 5. BB. 9265.

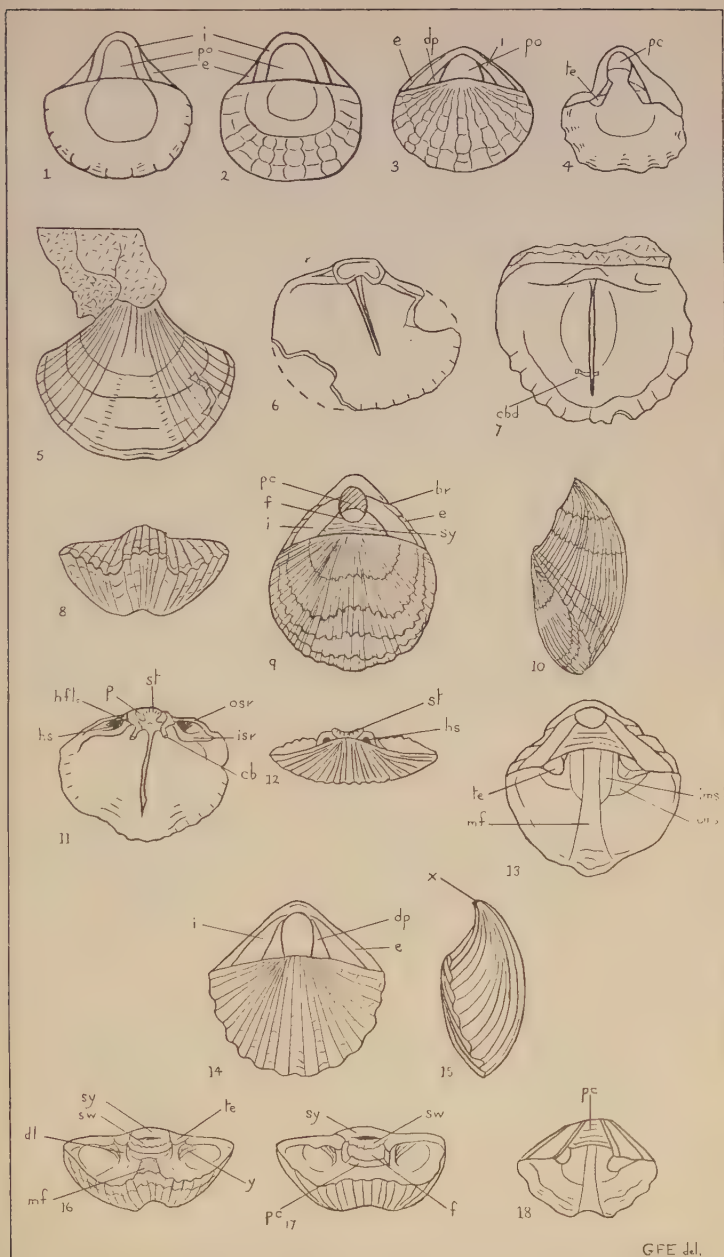
Enlargements are linear and approximate. "1.0mm. stage," etc., refers to shell-width. Side views of loops are lateral-oblique.

- ab = ascending branch.
 au = "ear" of campagiform to adult loop-stages.
 ba = broken ascending branch.
 br = beak-ridge.
 c = crural point.
 cb = crural base.
 cbd = connecting band from septum to descending branch.
 db = descending branch.
 dl = dental lamella.
 dp = deltidial plate.
 e = edge of pedicle valve.
 f = foramen.
 fl = pre-campagiform flange.

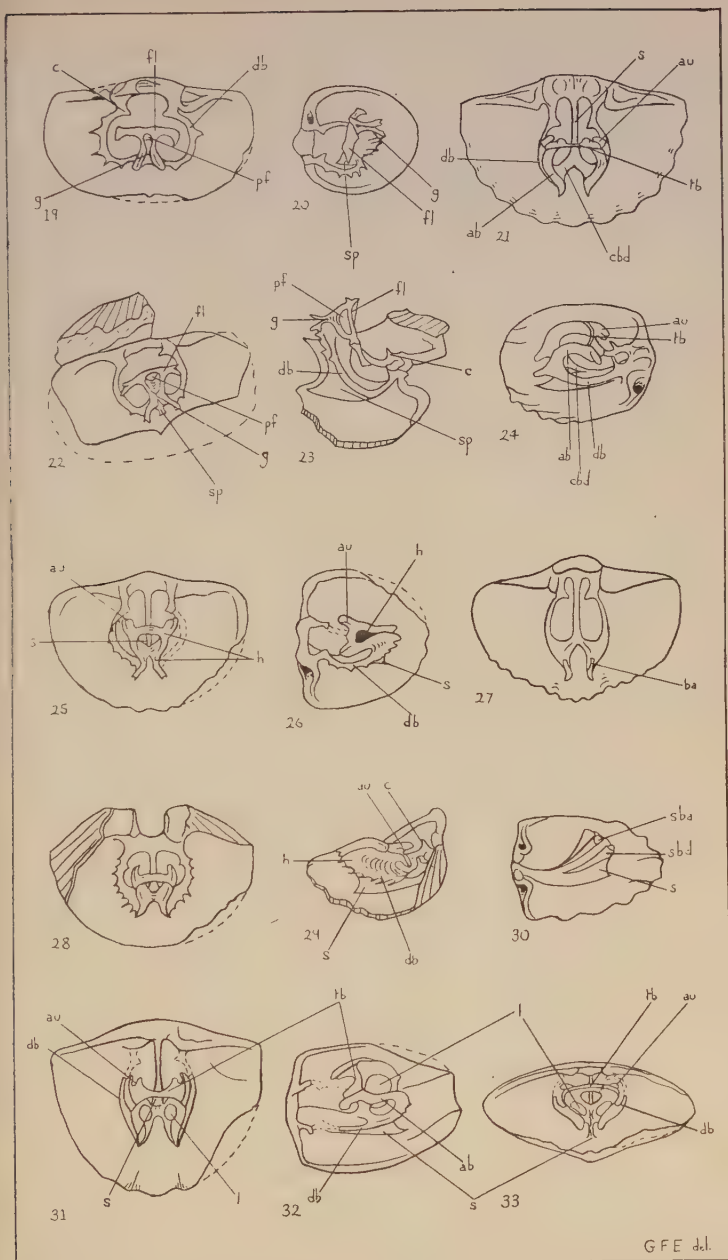
- g = groove of pillar.
 h = campagiform hood.
 hfl = flange of hinge-platform.
 hs = hinge-socket.
 i = interarea.
 ims = inner muscle-scar.
 isr = inner socket-ridge.
 l = frenuliniform lacuna.
 mf = median fold.
 oms = outer muscle-scar.
 osr = outer socket-ridge.
 p = boss of cardinal process.
 pc = pedicle-collar.
 pf = perforation.
 po = pedicle-opening.
 s = median septum.
 sba = attachment of broken ascending branch.
 sbd = attachment of broken descending branch.
 sp = septal pillar.
 st = striated area of cardinal process.
 sw = symphytial wedge.
 sy = symphytium.
 tb = transverse band.
 te = hinge-tooth.
 x = "spiriferoid" beak.
 y = lateral cavity of beak.

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CHERT FORMATION IN THE BARGATE BEDS OF THE CHURT NEIGHBOURHOOD, SURREY

By J. A. RICHARDSON, A.R.C.S., Ph.D., Assoc.Inst.M.M., F.G.S.

(Weald Research Committee Report, No. 35)

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I. INTRODUCTION AND REVIEW OF PREVIOUS LITERATURE

BETWEEN 1934 and 1936, H. S. Rogers and the writer mapped about 52 square miles of the north-western Weald lying between Thursley, Witley, Binstead and Bordon in Surrey and Hampshire, on the scale of six inches to a mile. An account of the geology of this area was written, and J. F. Kirkaldy kindly read a summary of the paper before the Association in January, 1937, on behalf of the authors, both of whom were abroad at that time. As fair copies of the maps had not been completed, the paper was never published, and, in the passage of the war years it has been lost.

The writer, recently repatriated from a P.o.W. camp in Siam, has re-discovered a paper written by him in 1936 on "Chert Formation in the Bargate Beds of Part of the North-west Weald."

The present communication combines part of the original Weald Research Committee Report referred to above, the gist of the paper on chert formation, data contained in notes and diagrams kindly returned by J. F. Kirkaldy and the results of field work recently carried out in Surrey. The area is shown in Fig. 10.

There is an extensive literature dealing with the Bargate Beds, but comparatively little has been published concerning the formation of the stone bands which they contain.

G. J. Hinde in 1883 described Top Chert exposed in a road-cutting halfway between Haslemere and Godalming. The chert comprised an upper and lower layer of "yellowish, porous siliceous

rock" with a core of "light to dark translucent chert" [5*, p. 405]; the zones graded one into the other. Numerous cavities, believed to be the empty casts of sponge spicules removed by solution after consolidation of the beds, occur in the outer layers, and this dissolved-out silica is presumed to have migrated inwards to form a core of more solid chert. The undissolved spicules are said to have very indefinite outlines and to be easily overlooked.

The Top Chert division forms the upper part of the Bargate Beds between Wotton and Headley. It varies considerably in thickness and attains its maximum around Stock Farm and Green Cross, Churt.

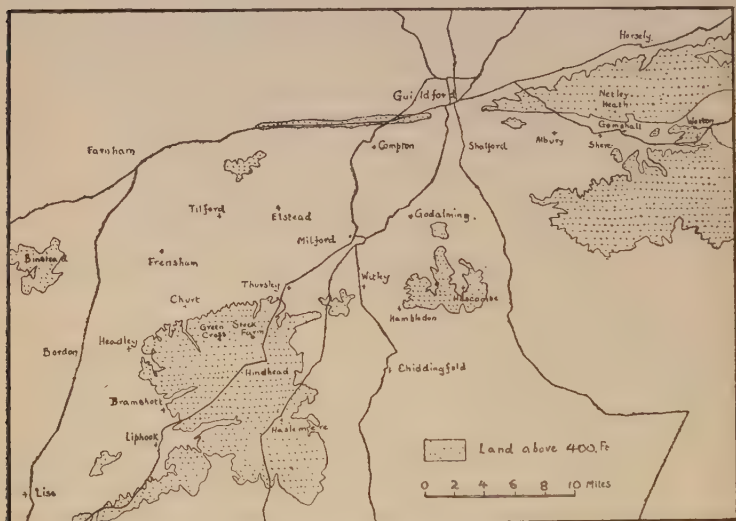


FIG. 10.—SKETCH-MAP OF THE AREA IN WHICH THE BARGATE BEDS HAVE BEEN EXAMINED.

F. Chapman in 1894, describing the Bargate Beds of Surrey, recorded the occurrence of chalcedonised sponge spicules and silicified shell fragments in the Bargate Stone in Littleton Lane quarry near Guildford [6, pp. 678–681]. He also described a hard siliceous rock in the lane leading to Great Halfpenny Farm, St. Martha's Hill, Chilworth. It contains only a trace of calcareous matter and consists almost entirely of quartz grains and sponge spicules of which the axial canals are filled with mammillated chalcedony [6, p. 682].

In 1932, H. A. Hayward recorded the occurrence in the Dorking-Leith Hill district of Hythe Chert said to be very similar to the Top Chert described by Hinde. This chert always occurs as the

* For List of References see p. 176.

core of sandstone layers. It consists mainly of chalcedony and contains detrital quartz grains and sponge spicules. Chalcedony also forms the bulk of the sandstones, but detrital quartz is more abundant than in the cherts proper and may form 25 per cent of the rock. Spicules are more numerous in the sandstone than in the chert [8, p. 13].

The writer suggests that had the central chert been formed by the percolation inwards of silica dissolved from spicules present in the outer zones as suggested by Hinde, then fewer spicules would be expected to occur there. Hayward, however, has recorded the opposite distribution.

Lenticular calcareous bands occur in the upper Hythe Beds at Raikes Hollow. In the hand-specimen they resemble the finer types of Bargate Stone. They are composed of angular quartz grains set in a calcite matrix, and contain calcite foraminifera in which the chambers are filled partly by chalcedony. Of these, Hayward wrote : " It is a moot point which is replacing the other " [8, p. 14].

A pebbly cherty sandstone at the base of the Folkestone Beds at Raikes Hollow is made up of angular grains in a matrix of chalcedony. Chalcedonic sponge spicules occur in it [8, p. 21].

Twenhofel wrote [2, p. 540] : " Siliceous sponge spicules have long been regarded as the source of the silica in flint and chert. Hinde⁸²⁹ has been the chief exponent of this view. . . . Tarr⁸³⁰ made a careful study of the material Hinde had studied (in some cases having identical materials), and found that sponge spicules were consistently absent from most slides." He recorded the view of soil chemists that there is little or no downward movement of silica save in the tropics where lateritic soils develop and concluded that the commonly accepted source for the silica in secondary chert is consequently removed [2, pp. 537-538].

To sum up : Hinde considered that the subsequent re-deposition of silica formed by the solution of sponge spicules could account for the formation of secondary chert, but he offered no explanation for the periodic flourishing of large sponge colonies. Chapman supported Hinde, and Kirkaldy has expressed the view that the silica thus formed is sufficient to bring about the extensive and, frequently very advanced silicification of calcareous Bargate Stone. Tarr, however, came to conclusions diametrically opposed to those of Hinde, and stated that most of the cherts contained few spicules or none, and Twenhofel rigorously questioned the organic theory of the formation of syngenetic chert.

II. CONDITIONS OF DEPOSITION OF THE BARGATE BEDS

Near Guildford the Bargate Beds are very coarse, badly graded, white to brown sands containing seams of calcareous sandstone.

Around Godalming they are finer grained and better graded and contain bands of doggers of hard siliceous limestone known as Bargate Stone. The "Godalming Facies" extends westwards through the Hascombe area [3, pp. 132-136] into the adjacent Witley-Thursley district. It becomes progressively finer in grain, until, west of Hindhead Nurseries, Thursley, the beds are fine-medium or medium-fine sands with stone doggers; here they are seldom pebbly. The "Churt-Green Cross Facies" continues westwards to Headley (Hants.), but the calcareous development may be greatly reduced or entirely absent between Prospect Hill and Headley (Fig. 10).

There was evidently a shore-line to the north, and the Bargate Beds were deposited on a platform shelving southwards and westwards from this [4, pp. 298-302]. The presence of glauconite accords with the view that sedimentation proceeded at no great distance from the "mud-line" surrounding continental shores [1, p. 519] and further evidence is supplied by current-bedding from north and east [3].

III. LITHOLOGY OF THE BARGATE BEDS AROUND CHURT AND HINDHEAD

Rogers and the writer found that the Bargate Beds of Churt and Hindhead are divisible into :

(i) Top Chert division : Cherts and sands.

(ii) Bargate Stone division : Calcareous sandstone, siliceous limestones, cherts and sands.

and that this succession accords with that established by Kirkaldy in the adjacent Hascombe area [3 and 4].

SECTION : GREEN CROSS PIT, CHURT, 1936.

Upper Beds.

Fine to medium, glauconitic, greenish-grey or brown sands with bands and nodules of sandstone and cherty sandstone	12'-15
--	--------

Middle Beds.

Upper : Sands with chert doggers formed from the original Bargate Stone	4' 10"-5' 6"
---	--------------

Lower : Sands with chert doggers containing small residual patches of blue, chertified Bargate Stone frequently with a limonitic cortex	5' 8"-6' 8"
---	-------------

Lower Beds.

Sands with doggers of blue-hearted Bargate Stone	18'
--	-----

Total about 41 feet

The Upper Beds are poorly silicified and contain little real chert. A well located nearby passed through 92ft. of Bargate Beds.

The cherts of the Middle Beds are frequently zoned :

- Top margin :
- (i) Pale, flaky, glauconitic sandstone.
 - (ii) Very vesicular, firm, brown chert.

- Core : (iii) Blue cherty Bargate Stone passing laterally into "rotten chert" and thence into
 Bottom margin : (iv) Incoherent limonitic sand.
 (v) Hard banded chert, often flaky marginally.

A chert band 20ft. below the surface, contained residual patches of good Bargate Stone traversed by calcite films. It had been extensively silicified.

During the war, this pit has been utilised as a Tank Training Ground ; most of the old excavation has been filled in and the pit is no longer worked. About 15–20ft. of strata were exposed here in January, 1946.

SECTION : SOUTH END OF GREEN CROSS PIT, CHURT, JANUARY, 1946.

	Feet
A. Soil and subsoil : Silty fine-medium sand, brown, rusty and buff	1½
B. Silty fine-medium sand, buff and rusty	2
C. Stone band : purplish and lilac grey, hard, fairly compact, slabby rock which splits into blocky joint fragments	1
D. Sand as in Bed B	½
E. Stone band resembling band C	¼–½
F. Silty fine-medium sand, ferruginous, dark rusty brown and speckled buff and brown	10
Section obscured by talus	

Total about 16 feet

Top Chert is less well developed here than in Stock Farm Pit which lies farther east along the strike of the Bargate outcrop.

Chert band E comprises an upper layer of hard stone more compact than that of band C, with a core of silty sand, incompletely chertified material and rotten rock deeply ironstained rusty brown. One specimen had a moderately compact ferruginous core enclosed on one side by concentric sheets, some $\frac{1}{16}$ in. to $\frac{1}{8}$ in. thick, of silty sand. These "plates" had the form and appearance of the concentric layers of a concretion.

SECTION : MIDDLE OF GREEN CROSS PIT, CHURT, JANUARY, 1946.

	Feet
A. Soil and subsoil	} 3½ to 4 circa 10.
B. Silty fine-medium sand, finely laminated	
C. Silty fine-medium sand containing stone bands :	

Bed C consists largely of silty fine-medium sands, slightly to moderately current-bedded, finely laminated and fairly evenly bedded. They are generally sage-green, greenish-grey and speckled with granular glauconite, concentrated along thin bands, and there are patches ironstained yellowish, buff, brown and rusty. Some bands are very dark brown.

The stone bands are lenticular, impersistent, elongate and thin.

They are white, whitish-grey, pale buff, and locally ironstained. The stone is laminated and banded, rough and hackly to the touch. It is porous and incompletely silicified. Characteristic features of the bands are :

- (i) Their occurrence as elongate concretions enclosed by the sands.
- (ii) Their porous, soft, poorly compacted cortex.
- (iii) The hard or moderately compact outer stone which encloses
- (iv) A core of deep rusty-brown, ferruginous silty sand, sometimes containing fragments of rotten chert.

The lower stone bands show progressive silicification and decalcification leading to the formation of ferruginous sandy cores enclosing fragments of rotten chert in the elongate doggers.

A dogger in the lowest band exposed in this section shows an advanced stage of decomposition. The upper and lower layers break along concentric planes. The upper stone is cherty and porous ; the lower stone strongly jointed, very compact, hard, blue-grey and sub-vitreous. The core is rusty brown, rather plastic sand.

Doggers showing similar features are abundant in higher bands farther north along the pit face.

Stock Farm Pit, Hindhead

This pit, at present unworked, is situated a little east of the road from Beacon Hill to the "Pride of the Valley," Churt, between Stock Farm and Marchant Farm.

SECTION : STOCK FARM PIT, HINDHEAD, 1936.

	Feet
Sands Group :	
Upper : Sands with bands of Top Chert	8
Lower : Sands with sandstones and cherty sandstones	10
Calcareous Group :	
Sands with doggers of calcareous and chalcedonic Bargate Stone	35
	Total 53 feet

The Top Cherts become less vesicular and porous from top to base.

SECTION : NORTH FACE OF STOCK FARM PIT, HINDHEAD, JANUARY, 1946.

	Ft.
A. Soil and cherty rubble	1
B. Ferruginous silty, fine-medium sand coloured reddish, rusty and brown. It contains four bands of Top Chert :	8
	ft. ins.
F. Chert	6
Sand	0

					ft	ins.
G.	Chert	...	...	...	...	9
	Sand	...	...	...	2	0
H.	Chert	...	...	...	1	0
	Sand	...	...	...	1	6
J.	Chert	...	...	...	1	0
C. Sage-green and grey-green, speckled, glauconitic, silty fine-medium sand with interbedded layers of Top Chert.						
	Sand	...	...	...	...	Ft. ½ to 1
K.	Stone	...	...	...	...	1
	Sand	...	...	...	...	1
L.	Stone	...	...	...	...	1
D. Green sand as in Bed B, containing numerous tiers of calcareous and siliceous doggers of Bargate Stone (including band M, the topmost)						
		...	...	...	...	at least 35
Total about 48 feet						

Bed B consists of typical Top Chert. It is brown, honey, purplish or rusty in colour. It is splintery, strongly jointed, and breaks readily into angular blocks.

The cherts of Bed C are lenticular and have probably been produced by the alteration of Bargate Stone doggers. They occur as long, rather narrow lenses, containing cores of loose, ironstained sand and raggy chert fragments identical with those recorded in Green Cross Pit. Seams and veinlets of opalescent purplish-white chalcedony coat the walls of some fissures in the chert.

Bed D, immediately below, contains the highest calcareous Bargate Stone (Band M) exposed in this pit.

The typical Bargate Stone occurs as doggers as large as 12ft. x 6ft. x 2½ft. It is medium to fairly coarse grained, cemented by calcite, by calcite and chalcedony together, or by chalcedony alone. The colour is blue-grey, lilac, purplish and sometimes buff, speckled greenish with glauconite. The doggers are traversed by well-defined joint-planes and bedding-planes along which they fracture into rectilinear blocks. The current-bedding and finely-spaced lamination of the enclosing sands are continued without hindrance through the doggers, thus proving that they grew *in situ* where they now are found. The stone becomes softer, raggy and porous, partially bleached and locally ironstained as the removal of the calcite matrix proceeds.

IV. PETROLOGY OF THE STONE BANDS

The stone bands of the Bargate Beds belong to three groups :

(i) The Stone Bands of the Top Chert Division.

(a) Typical Top Chert.

(b) The Cherts and Cherty Sandstones of Green Cross Pit.

(ii) Non-calcareous Sandstones and Cherty Sandstones composed of quartz sand and glauconite more or less completely cemented by chalcedony. There are three varieties :

- (a) Feebly consolidated greenish-grey sandy rock.
- (b) Rather friable greenish sandstone.
- (c) Fairly hard greyish to purplish-grey Cherty Sandstone.

Not infrequently, sandy types have harder, more compact chertified cores. These rocks are found in both the Top Chert and Bargate Stone Divisions.

(iii) The Bargate Stone, comprising :

- (a) Coarse "shelly" type.
- (b) Fine-medium grained type.

The several varieties dependent upon the composition of the matrix, include :

- (a) Calcareous Bargate Stone, siliceous limestone and calcareous sandstone.
- (b) Calcareo-siliceous Stone.
- (c) Calcareous Chert (Chert containing calcite organisms).

(i) The Stone Bands of the Top Chert Division

The stone bands in Green Cross Pit are porous, rubbly, purplish and lilac-grey sandy cherts. They are composed of fairly well graded, fine-medium grained quartz, a little quartz mosaic, small pellets of red-brown limonite and ironstone, spherical and ovoid glauconite, some of it partly limonitised, and silicified organic remains set in a chalcedonic base. Both terrigenous constituents and organic fragments tend to occur in bands and laminae, but they are also scattered throughout the chert. The chalcedony is full of cavities and many of the pores have cusped margins due to its mammilliform crystallisation. The chalcedony is present as very fine grained mosaics exhibiting strongly banded, colloform, and agate structures, and cusped mammillated forms. Much of it occurs as radially arranged needles.

The cherts contain many dusky and somewhat ironstained subtransparent bodies identical in shape and form with the organic fragments found in calcareous Bargate Stone. Some have marginal outgrowths of scalenohedra which must originally have been calcite ; now they are replaced by quartz or chalcedony (Fig. 11, ii, iii, vi). Fragments of silicified echinoid spines and plates identical with them have been detected also in chert bands C, E and the lowest in Green Cross Pit. Spines, circular or ovate in cross section, have a core of very fine grained chalcedony mosaic, rimmed by a thin cortex of radially arranged fibrous chalcedony pseudomorphous after the original fibrous calcite of the spine casing. An example from chert band L in Stock Farm Pit is shown in Fig. 11, vi.

Chert bands J and L in Stock Farm Pit contain similar material. They are almost identical with the chalcedonic Bargate Stone lower in the succession and obviously were formerly shelly sands.

(ii) The Bargate Stone

The main difference between the coarse "shelly" type and the fine type of Bargate Stone is the greater abundance and larger dimensions of the organic detritus in the former. Quartz forms the bulk of both varieties of calcareous stone. It is concentrated locally into bands or laminae and is also scattered through the

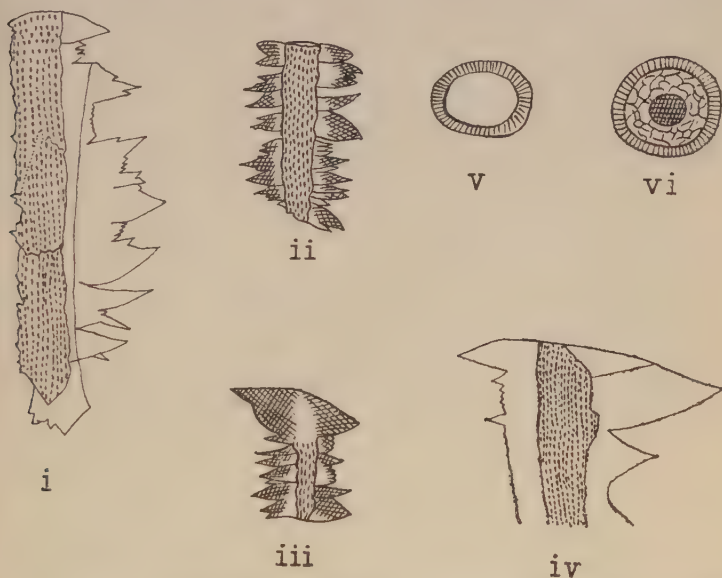


FIG. 11.—MINUTE FOSSILS IN THE CHERTS, SHOWING STAGES OF REPLACEMENT (see text).

rock, together with grains of glauconite, limonite, lydite, ironstone, quartz-mosaic, and a few fragments of microcline and acid-plagioclase, set in a fine grained base of crystalline calcite. A few phosphatic pellets, fragments of chert and Jurassic ooliths are also present. The terrigenous fragments are fine to medium-grained and generally fairly well graded.

The organic material includes comminuted echinoid tests and spines, foraminifera, shells, polyzoa and a few chalcedonic sponge spicules. Except for the spicules, the remains are preserved mainly in calcite and many have marginal outgrowths of clear scalenohedra interlocking with the base (Fig. 11, i).

Many of the doggers have been incipiently silicified and these contain chalcedony in the base and in the chambers of calcite foraminifera.

There are, in addition, siliceous Bargate Stone doggers, in which the base is wholly colloform chalcedony. Their grain composition and organic content are identical with that of the calcareous stone.

Chalcedonic Bargate Stone from the first tier of doggers (band M) in Stock Farm Pit, some 12ft. below surface, is crowded with organic remains, most of them margined by outgrowths of secondary scalenohedra in optical continuity with that of the fragments (Fig. 11, iv). Chalcedony occurs in the chambers of foraminifera and has completely replaced some calcitic organisms. The base of the rock is entirely chalcedony and exhibits the same microstructures described in the Top Chert. Minute spaces left between adjacent walls of mammillated chalcedony have been filled by clear quartz. The clastic quartz grains of the rock are usually full of dust inclusions, have clear-cut margins and show no sign of marginal recrystallisation or the slightest encroachment of the chalcedony. Identical microstructures, calcareous and siliceous organic remains occur in chalcedonic doggers 37ft. and 44ft. below surface, and also in the lowest band of stone.

Coarse calcareous Bargate Stone from Stock Farm Pit contains echinoid remains with the usual marginal scalenohedra (Fig. 11, i). Some of the organic fragments have been partially replaced by glauconite. Threads, patches and filaments of very fine grained or almost cryptocrystalline chalcedony occur in the calcite matrix, and a few chalcedonised sponge spicules are present.

It is uncertain whether the chalcedony in this rock is contemporaneous with the calcite or whether it has been introduced subsequently.

Doggers of fine to medium-grained siliceous limestone, containing fairly abundant organic remains, used to be exposed in Green Cross Pit. They all showed incipient chalcedonisation of the base. One sample contained interstitial chalcedony tongues between the quartz grains, wrapped around the glauconite and amidst the calcite mosaic.

Sponge spicules occur in some of the cherts and calcareous stone bands. As a rule they were not abundant in the slides examined by the writer. No spicules were observed preserved in opal; all had been converted into chalcedony or quartz. It was observed that rather vague canal-like and tube-like microstructures common in the matricial chalcedony of most of the siliceous rocks tend to simulate the forms of single- or multi-branchate sponge spicules. They are, however, not of organic origin. These structures are formed by the ultimate crystallisation of chalcedony, or sometimes of clear quartz, between closely approaching walls of chalcedony. It is possible that this accidental resemblance of

inorganic colloidal structures to organic spicules misled Hinde into believing that many cherts examined by him had been originally sponge beds. Tarr, who re-examined Hinde's material together with numerous other specimens of chert, came to the conclusion that spicules were consistently rare or absent in the rocks. The writer's observations in general, are in fair accordance with those of Tarr, and support the view that the cherts present in the Bargate Beds were not originally "sponge-spicule beds."

V. PALAEONTOLOGY

The coarse Bargate Stone exposed around Churt contains comminuted organic remains in abundance. Remanié fossils from the Jurassic also occur in it. Similar material is rather less common in the finer types of Bargate Stone and in the Top Chert.

E. A. Turner submitted two specimens from Green Cross Pit to the Geological Survey and Museum at Jermyn Street in 1929. Dr. Kitchen reported that they were :

Martesia sp. (in wood).

Parahoplites aff. *Nutfieldensis* (J. Sow.).

The ammonite was named by Dr. Spath who placed the beds as Upper Aptian, Sandgate Beds (letter to E. A. Turner from H. G. Dines, dated 7th June, 1929).

H. S. Rogers and the writer submitted a small collection of material to Dr. H. D. Thomas, British Museum, Natural History, in 1936. He made the following identifications, conjointly with C. D. Ovey :

Nonion ? sp.

Textularia sp. cf. *sagittula* (de France).

Textularia sp.

Cristellaria sp.

Polymorphina ? sp.

In addition, he recorded the presence of fragments of crinoids, indeterminate polyzoa and foraminifera. (Note to the writer from H. D. Thomas, dated 25th July, 1936.)

Sponge spicules occur in some of the Stone bands in the Bargate Beds. They are not abundant as a rule.

VI. SUMMARY AND CONCLUSIONS

The data presented above may be summarised as follows :

1. The calcareous stone bands of the Bargate Beds have been decalcified, and silicification has followed closely upon the removal of the calcite. These processes may be still in operation.

(i) The rocks first become rather porous, friable and brownish due to ironstaining.

- (ii) With increasing loss of calcite they become very porous and flaggy, and split readily along bedding-planes.
- (iii) When decalcification is almost complete, the rocks revert to loose, incoherent plastic sand containing fragments of rotten, raggy chert, patches of "chert meal" and residual core-fragments of partially decalcified stone.

2. Silicification has accompanied decalcification almost simultaneously according to the following stages :

- (i) The occurrence of chalcedony in the base and in the chambers of foraminifera.
- (ii) The complete chalcedonisation of the base and of some organic fragments, the most advanced stage observed in calcareous Bargate Stone.
- (iii) Complete replacement of the organic débris by chalcedony and quartz, and the development of a porous chalcedonic matrix in the Top Chert and sandy cherts.

3. At Stock Farm Pit, silicification is incomplete in the upper Sands Group, for the cherts are highly vesicular. The lower Sands contain chalcedonic silica and the Calcareous Group below may show complete groundmass silicification even 50ft. below surface.

4. At Green Cross Pit, silicification is slight and irregular in the Upper Beds, very extensive in the Middle Beds and slight in the Calcareous Beds below. This distribution of secondary silica precludes all possibility that silicification of the Middle Beds was caused by the descent of silica from the Upper Beds or by its ascent from the underlying Hythe Beds.

5. Organic fragments in the Bargate Stone and Top Chert have marginal scalenohedra ; those in the chert have been replaced by quartz. Rosettes of chalcedony have been moulded on them [1].

6. Interstitial chalcedonisation of the base of the limestones is common.

7. Chalcedonic sponge spicules are present in some of the stone bands in the Bargate Beds. They are seldom abundant. The spicules observed by the writer in the Bargate stone bands were clearly defined, easily recognisable and showed no trace of solution. These observations are in accordance with those of Tarr who disputed Hinde's contention that the Bargate cherts had originally been beds of sponge spicules.

8. Where silicification is extensive as in the Middle Beds at Green Cross Pit, and the lower Sands Group at Stock Farm Pit, limonite is invariably abundant in both cherts and associated sands. Some of it may have been released by the oxidation of glauconite, but most of the glauconite has remained unaltered.

It is possible, therefore, that some of the ferric hydrate was precipitated directly from sea-water [2, pp. 434 and 530].

9. In much of the Bargate Stone the quartz grains are not in contact one with another, and their arrangement is not that of normal sandstone. Some of the terrigenous material, however, occurs in distinct laminae and bands parallel with the bedding of the enclosing sands.

10. Similarly, the Top Cherts consist commonly of a porous chalcedony fabric enclosing scattered grains and sponge spicules [8, pp. 13-14].

The fairly rapid accumulation of either lime or silica-gel is essential to account for the distribution of clastic grains and organic fragments described in 9 and 10 above.

In the Bargate Beds we have to consider the double problem of (i) the formation of cherts and their association with siliceous limestones, and (ii) the presumed silicification of the limestones.

Three main theories concerning the formation of chert must be considered :

- (i) That cherts have been formed organically by the solution, re-distribution and subsequent re-deposition of silica contained largely in sponge spicules.
- (ii) That cherts have been formed by direct electrolytic precipitation of silica-gel from sea-water in comparatively shallow coastal waters.
- (iii) That silica-gel, precipitated electrolytically along with sedimentary detritus, is subsequently re-dissolved and later re-deposited as beds, nodules and lenticles.

Referring to the first theory, it is considered highly improbable that the Bargate cherts have been formed wholly from sponge spicules. The maximum thickness of the Top Chert Division is about 18ft. around Stock Farm and Green Cross, and of this thickness, less than half is actually chert ; the remainder is sand. Had the Bargate cherts been originally beds of sponge spicules, solution *in situ* of such material and the recrystallisation of the silica-gel thus formed might have produced a porous rock resembling Top Chert. It is very unlikely, however, that enough silica would be forthcoming from such a process operating upon not more than 10ft. of " spicule rock " to cause the extensive silicification observed in at least 30ft. of the underlying strata, of which more than half are formed of Bargate Stone and chert doggers. It is known, moreover, that the Top Chert was not originally such a " spicule rock " for it contained considerable volumes of quartz, glauconite and calcareous organic remains.

Some of the silica of which the cherts are made may have come from spicules as Hinde has suggested, and some, also, from the

decomposition of glauconite (most of the glauconite is, however, still fresh). It is unlikely that the quantities of silica-gel needed to cause both the advanced degree of silicification seen in the Top Chert itself, and the very advanced chalcedonisation of the underlying Bargate Stone could possibly have been derived in this way.

Kirkaldy has remarked that the decrease in the degree of silicification from top to bottom of the Bargate Beds around Churt is contrary to the view that silica was introduced by upward percolation from the underlying Hythe Beds.

The occurrence in both Top Chert and calcareous and chalcedonic Bargate Stone of laminae of quartz sand and organic debris, and the continuation in them of the stratification and current-bedding of the enclosing sand proves that they grew *in situ*. The suggestion, put forward by Tarr and quoted by Twenhofel [2, pp. 541-542, Ref. 839) that organic matter, and presumably also terrigenous material in cherts, are picked up by the rolling by wave-action of masses of sticky silica-gel in shallow seas, or by their falling into the gel, does not hold for all the stone bands of the Bargate Beds. Such a process is unlikely to have led to the introduction of parallel bands of grains in the cherts. Some of the cherts, consisting largely of chalcedony with scattered clastic grains, were, however, doubtless formed in this manner.

It is suggested that the conditions under which the Bargate Beds accumulated, on a shelving continental-platform near the "mud-line," where glauconite also was forming, were admirably favourable to the electrolytic deposition of silica-gel. The rhythmic building up of the gel in the coastal waters until a precipitation concentration had been attained, followed by its electrolytic deposition, might well explain the variability in its distribution in adjacent strata and the variable characteristics of the cherts and presumed certified limestones now present in many of them.

It has been shown that the Top Cherts contain organic fragments rimmed with chalcedony or quartz, pseudomorphous after secondary calcite scalenohedra identical with those present in the calcareous Bargate Stone. The Top Chert beds must have been shelly sands like those beneath them which later became Bargate Stone. It is considered that the microstructures observed in the Top Cherts, the shape, form and appearance of the chert masses, the incomplete silicification leading to the formation of incoherent sandy cores, of rubbly chert, "chert meal," and plastic silty ferruginous sand lenticles enclosed by fairly hard chert, all point to their having been formerly like the calcareous Bargate Stone doggers in which similar features have been observed. It is concluded, therefore, that the Top Cherts also may have passed through a stage during which they too were calcareous "shelly" sandstones or siliceous limestones, before becoming converted into cherts. Some of the

Top Chert and chalcedonic Bargate Stone is well-nigh identical, except that the Top Chert is generally more ironstained and the Bargate Stone contains calcite organisms.

It is suggested that the bulk of the silica needed to form the cherts, probably all of it, was laid down as silica-gel by direct electrolytic precipitation from sea-water in the neritic environment. Such colloidal silica is thought to have been partly dispersed through the "shelly" sands and partly concentrated as lenticular masses and bands, and to have been more abundant in some strata than in others. The distribution of the siliceous bands in the Top Chert division and the chertified Bargate Stone below it is variable and does not conform with any simple linear zoning. The distribution of chalcedonic silica in the various beds seems to be lenticular. The suggestion that silica-gel was originally more abundant in some localities and at some horizons than in others adjacent readily explains both the vagaries of distribution of cherts in the Bargate Beds and also affords a reason for the abundance of sponge spicules in some places and their paucity in others; for the sponges must be dependent upon the amount of soluble silica available.

In conclusion, therefore, it is suggested that the conditions of deposition under which the Bargate Beds were accumulated approximated to the following:

1. Laminated and current-bedded silty glauconitic sands were laid down and these contained calcareous organic detritus, spicules were more abundant in some beds and scarcer in others. The sands contained also variable quantities of silica-gel deposited electrolytically, in some beds dispersed, in others concentrated as elongate masses.

2. Some of the carbonate in the sands migrated and became concentrated in doggers of siliceous limestone, and during this period the organic fragments commonly became recrystallised and developed marginal outgrowths of calcite scalenohedra. Tiers of such limestone doggers may have been formed at spaced intervals from top to bottom of the Bargate Beds.

F. W. Clarke [1] has stated that in a silt containing both calcite and silica-gel, the calcite will crystallise out first, whereas the silica, which is slower to crystallise, and seldom progresses far beyond the semi-crystalline chalcedony stage, moulds itself on to the calcite already solidified in the form of rosettes. This exact relationship is clearly seen in the calcareous and chalcedonic Bargate Stone and in the Top Chert, where, however, the organic remains themselves have been silicified.

3. Probably at no great time after the crystallisation of the calcite groundmass in the limestones, silicification began with the concentration of dispersed silica-gel in the sands and its consolidation as chalcedony. It pseudomorphed some of the organic

material and may have replaced part of the calcite base of the limestones.

4. Silicification proceeded strongly or slightly, dependent upon the amount of silica originally present in the sandy beds. Such a process would explain the very irregular degree of silicification observed, whereby doggers 50ft. below surface are wholly chalcedonised with the exception of resistant organic fragments, whereas, others nearer the surface are scarcely silicified at all.

5. Silicification is most advanced in the Top Chert division, for here all the organic remains are preserved in secondary silica, but it has not been complete because these cherts are still vesicular. It appears, therefore, that the sands forming the upper part of the Bargate Beds contained initially more silica than did those of the underlying beds.

6. An alternative suggestion is submitted tentatively. It is conceivable that :

- (i) Some of the cherts and sandy cherts of the Top Chert division were laid down originally as chalcedonic rocks containing clastic grains and organic fragments which later became chalcedonised. If this were so, then some of them must have solidified fairly rapidly in order to account for the wide dispersal of sedimentary grains in rocks of which the bulk is groundmass chalcedony.
- (ii) Some of the chert doggers in the Bargate Stone division (containing calcareous organic fragments, but no other source of calcite) do not represent the penultimate stage of secondary silicification of limestones as has generally been assumed hitherto, but were formed initially as cherts in which the organic material has remained unchanged. Tarr suggests that the survival of calcite organic material under such conditions of deposition is by no means uncommon.

VII. ACKNOWLEDGMENTS

The writer thanks G. S. Sweeting and J. F. Kirkaldy for reading the paper and offering criticisms and suggestions, and Dr. H. D. Thomas and C. D. Ovey for their identifications of fossils submitted to them.

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THE WORK OF THE LATE MR. FRANK GOSSLING ON THE STRATIGRAPHY OF THE LOWER GREENSAND BETWEEN BROCKHAM (SURREY) AND WESTERHAM (KENT)

By J. F. KIRKALDY, D.Sc., F.G.S., F.R.Met.Soc.

(Weald Research Committee Report No. 36)

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I. INTRODUCTION

MR. FRANK GOSSLING commenced work on the Lower Greensand in 1924. For the next 15 years, until interrupted by the outbreak of war, he made a very detailed study, including mapping on the scale of six inches and, locally 25 inches, to the mile of the 15-mile stretch of outcrop between Brockham in the west and Westerham in the east (Fig. 12). He returned to Croydon in 1943 and immediately before his death, though in his 87th year, was making plans for the resumption of his work, having already done some preliminary fieldwork.

Mr. Gossling's published work on the Lower Greensand is embodied in two long papers [1*] and [2] and four shorter notes [3], [4], [5] and [6], but he was always reluctant to rush into print, and his investigations were much further advanced than his published work would suggest. He bequeathed his large collection of field maps, diagrams, notebooks and specimens to the Weald Research Committee. The following pages have been compiled from these data, supplemented by the writer's recollections of many days spent together in the field or in discussion. They summarise Mr. Gossling's long-continued researches on some of the problems of the Lower Greensand.

* For List of References see p. 191.

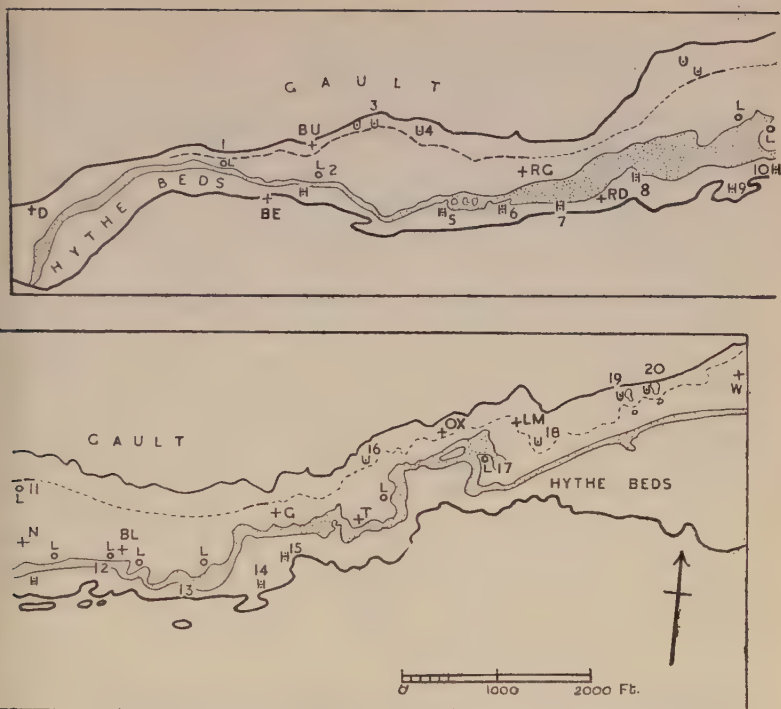


FIG. 12.—GEOLOGICAL MAP OF THE AREA EXAMINED BY THE LATE MR. F. GOSSLING.

Northern thick line—Base of the Gault.

Southern thick line—Base of the Hythe Beds.

Stippled—Outcrop of the Sandgate Beds.

Chain line—Outcrop of the Clay-Silt Band Horizon in the Folkestone Beds.

Exposures of Pebble Beds are indicated by a modified letter H for Upper Hythe Beds ; L with small ring for Lower Folkestone ; and letter with dot for Upper Folkestone Beds.

The numbers indicate the following localities, which are referred to in this and the succeeding paper :—

- | | |
|---|-------------------------|
| 1. Bramble Wood. | 11. Pendell Court. |
| 2. Wonham Hill. | 12. Outwood Lane. |
| 3. Pit by Lawrence Farm, Buckland. | 13. Mitcheners Bank. |
| 4. Buckland Sand and Silica Co.'s Pits. | 14. Tilburstow Common. |
| 5. Park Lane. | 15. Taylors Hill Pit. |
| 6. Bell St. and Cockshot Hill. | 16. Priory Pit, Oxted. |
| 7. Woodhatch Brickyard. | 17. Oxted Roadside Pit. |
| 8. Redstone Hollow. | 18. Lord Rodney Pit. |
| 9. Bower Hill. | 19. Westwoods Pits. |
| 10. Mid Street, Nutfield. | 20. Squerrye's Pits. |

The large letters mark the site of the following churches :—

- | | |
|------------------|-----------------|
| BE. Betchworth. | LM. Limpsfield. |
| BL. Blechingley. | OX. Oxted. |
| BU. Buckland. | RD. Redhill. |
| D. Dorking. | RG. Reigate. |
| G. Godstone. | T. Tandridge. |
| N. Nutfield. | W. Westerham. |

II. THE TRACING OF LITHOLOGICAL DIVISIONS IN THE LOWER GREENSAND

The following four major divisions are recognised in the Lower Greensand of the Weald :

Folkestone Beds.
Sandgate Beds.
Hythe Beds.
Atherfield Clay.

In the present state of our knowledge they are based almost entirely on lithology. The beds were laid down in the "Belt of Variables" and as a result there is considerable variation, both vertically and horizontally, in the lithological characters of the major divisions. There exists some difference of opinion as to how frequent is this lithological variation. Gossling's view is summarised in the following quotation : "Here the Director referred to the importance, in correlating the subdivisions of the Lower Greensand, of first ascertaining the extension along the strike of such beds or seams as not only present distinctive characters, which can be readily recognised in small exposures, but also maintain these characters along a stretch of outcrop of, say, five to 10 miles or more in length. Such beds serve as datum lines of horizon to which less persistent beds could be referred" [5, p. 322]. He attempted to subdivide the major divisions into a number of minor lithological units each of which might be traceable for only a limited distance. He was of opinion that by obtaining a thorough knowledge of the character, thickness and persistence of these minor lithological units, a complete picture of the stratigraphy of the beds and the conditions under which they were deposited would be gradually built up. Further there were certain structural problems of the area which could only be unravelled by such detailed stratigraphical knowledge. In broad outline a somewhat similar view had been stated earlier by Leighton [7].

Gossling built up his detailed local succession by a combination of thorough and painstaking fieldwork and intensive laboratory examination of specimens ; particular use being made of the method of Mechanical Analysis. His aim was to establish diagnostic criteria for each lithological unit ; criteria which were independent of the oft puzzling effects produced by different degrees of weathering of these glauconitic sediments. The writer is convinced from his own experience that there is a limit to which one can trust even a thoroughly trained "eye" in deciding the correct horizon of these strata in deeply weathered exposures.

The officers of H.M. Geological Survey, who worked across the greater part of the ground now under discussion in 1928-30, whilst dividing the Lower Greensand into the same four major divisions, were sceptical as to the persistence of the minor lithological units

recognised by Gossling [8]. There is also considerable variation in places between the boundary lines shown on the official, and on Gossling's manuscript maps. They also criticised the value of Mechanical Analysis [9] and in his reply [4], Gossling pointed out that they had misunderstood his methods and claims. He used Mechanical Analysis not to separate the Folkestone Beds as a unit from the Hythe Beds as a unit, but to decide whether, for example, a particular pebble-bed should be correlated with pebble-beds noted elsewhere in the Hythe Beds or with the pebbly horizons found in undoubted Folkestone Beds. The same argument applied to the beds of medium sand, silt, etc. In his 1929 paper, Gossling based his criteria for such correlations almost entirely on the grading of the different beds, but subsequently he paid nearly as much attention to the proportion of the various constituents of the samples, e.g. percentage of glauconite grains, nature of any cementing material, types of pebbles present, etc. One point that Gossling did not make fully in his reply was that his critics had based their negative conclusions on 24 samples taken from a stretch of outcrop 14 miles in length. Gossling's faith in the value of Mechanical Analysis as an aid to geological mapping was based on more than 10 times as many samples collected from a considerably smaller area of outcrop. It may perhaps be suggested that inadequate sampling had merely revealed the presence of seams of coarse pebbly sand, medium sand, etc., in both the Hythe and the Folkestone Beds, while thorough sampling had developed criteria for distinguishing the pebbly horizons, etc., of the Hythe Beds from those occurring in the Folkestone Beds.

The writer is convinced that Mechanical Analysis is a very valuable tool to anyone working on the Lower Greensand, but that it must be used intensively. Where the structures are simple, exposures good and the lithological divisions well defined, it is perhaps an unnecessary elaboration of the ordinary mapping technique, especially as many workers are unable to spare the very considerable amount of time required. Where, however, structure is debatable and every scrap of evidence must be obtained from often inadequate exposures or auger holes, then Mechanical Analysis, based on well-established criteria and including the careful scrutiny of the constituents of the various grades, may be of great value.

III. THE DETAILED STRATIGRAPHY OF THE BEDS

Some 10 years ago the writer suggested to Gossling that he should prepare a series of detailed column sections of the area which he was investigating. Amongst Gossling's papers were found much material relating to this. It has formed the basis for Plate 6. The various grades of sand shown can be defined more precisely in terms of mechanical composition by comparison of columns 1 and 3 of this Plate with Fig. 13 below.

(a) Atherfield Clay.

As always in the Weald, this division was very poorly exposed. The complete sequence could be determined only at Woodhatch Brickyard, south of Reigate (265488)¹ [1, pp. 216-220] and around Bower Hill, S.W. of Nutfield (298497) [2, pp. 364-7]. To summarise, at Bower Hill, 7ft. of very tough, homogeneous, chocolate clay overlay 16 to 18ft. of grey to buff-coloured coarse silt; but at Woodhatch the upper seven of the 38ft. present, whilst of a chocolate tinge was not a true clay, but a clayey silt. It was underlaid by pale-coloured, often greyish silts with in the middle a six-inch seam of red brown fine sand. Elsewhere, indications of the presence of Atherfield Clay along the foot of the escarpment formed by the more resistant members of the Lower Greensand were frequent, but only in small "mapping" exposures and auger holes.

At Bower Hill, Gossling developed the following criteria for distinguishing between the Atherfield and the Weald Clay:

(1) The proportion of the clay and fine silt grades removed by decantation. This was about 70 per cent in the case of the chocolate clay, 30 per cent amongst the coarse silts and about 80 per cent for undoubted Weald Clay.

(2) Microscopic examination of the residues after decantation. In the case of samples from the Atherfield Clay, this consisted of quartz grains, sometimes stained with limonite; but Weald Clay samples contained a considerable proportion, in some cases as high as 60 per cent, of composite grains of fine silt or clay particles with a limonitic cement.

It is exceedingly valuable to have a reliable means of distinguishing between Atherfield Clay and Weald Clay, especially when weathered. This method has been successfully used by other members of the Committee.

As the Woodhatch section is now being filled in, it is desirable to put on record the following tabular statement of the percentage variations in grading of the Atherfield Clay and the highest beds of the Weald Clay:

	<i>Fine silt and clay.</i>	<i>Coarse silt.</i>	<i>Fine sand.</i>	<i>Medium sand.</i>
Basal Hythe Sand	6	53	41	
Atherfield Clay 1ft. down	29	56	15	
6,, ,	29	63	8	
11,, ,	55	45		
22,, ,	53	46	1	

¹ Advantage has been taken of the National Grid superimposed on the new Sixth Edition of the Ordnance Survey topographical maps to give a six-figure reference for each locality mentioned. Doubtless many others like the writer have often experienced great difficulty in finding exposures mentioned in papers, even after the passage of only a few years. Pits frequently change hands or are filled in and built over. Roads have been known to have their names changed. Much enquiry may be necessary to find the site of "Brown's pit, 1 mile S.W. of Church." The reference given above permanently locates within a square of 100 metres sides each exposure mentioned.

		<i>Fine silt and clay.</i>	<i>Coarse silt.</i>	<i>Fine sand.</i>	<i>Medium sand.</i>
Basal Hythe Sand	27ft. down	13	86	1	
Atherfield Clay	31, " "	15	85		
	36, " "	39	52	5	3
	41, " "	24	76		
	42, " "	15	84		
Weald Clay	Top	48	49	3	
	3ft. down	44	49	6	
	6, " "	50	46	3	

It will be seen that both the top and the bottom of the Atherfield Clay are marked by a sharp change in the mechanical composition of the sediments. The slightly greater thickness of the Atherfield Clay is a result of re-examination of the sections after 1929.

(b) Hythe Beds.

In his 1929 paper Gossling gave a full account of the beds between Brockham and Redhill and in particular a detailed section of the beds at Redstone Hill (now Redstone Hollow) Redhill (284497) [1, pp. 220-25]. Since then he had kept under observation the pits in Bell Street and Cockshot Hill, Reigate, and by 1935 these had been enlarged sufficiently to show the following almost complete section through the Hythe Beds :

Base of the Sandgate Beds.

Unexposed	...	...	...	...	...	8ft. at max.
Bed 4.	Whitish or buff, ill-graded, coarse or very coarse sand with pebbles of quartz and lydite ¹ set in a matrix of silt. Three thin bands of nodular siliceous sandstone					22ft.
Bed 3b.	Coarse and medium pale to red coloured sands with scattered quartz pebbles. Derived fossils included <i>Quenstedtoceras mariae</i> (d'Orb)					55ft.
Bed 3a.	Medium to fine bright-buff coloured sands with a few scattered pebbles. A seam of large nodules of sand cemented by limonite about 5ft. above the base has yielded <i>Tropaeum bowerbanki</i> (Sow) and <i>Nautilus</i> sp.					25ft.
Bed 2.	Greyish fine or medium sands without pebbles. A band of Fuller's Earth 6in. to 1ft. in thickness underlain by hard calcareous nodules near the top and in the lower part several layers of soft nodules and spicular sandstone					41ft.
Bed 1.	Very well graded fine sands, light buff in colour. Becoming more silty towards the base					54ft.

Total thickness 197ft. exposed.

The variations in the grading of the sands throughout this section are shown in Fig. 13.

Bed 4 and almost the whole of 3b were exposed in Hall's (Barnard's pit of the 1929 paper) on the east side of the road

¹ Lydite is here used as a convenient "omnibus" term to cover the many varieties of pebbles of chert and other rocks. In the succeeding paper [10] will be found a detailed description of these pebbles.

(258495), then there is a gap of perhaps 10ft. and on the west side of the road Lavender's upper pit was cut in Bed 3a and the greater part of Bed 2 and Lavender's lower pit (255492) in Bed 1.

If this section is compared with that at Redstone Hill [1, p. 255], it will be seen that there is very close agreement, though Bed 3 was not there subdivided. One very significant difference is the appearance at the top of Redstone Hill above the pebble bed (Bed 4) of 6ft. of "thin flaggy spicular cherty sandstone separated by glauconitic silt" and overlain by Fuller's Earth. On p. 237 of his 1929 paper Gossling grouped this bed with the Sandgate Beds; but subsequently for reasons which will be discussed later,

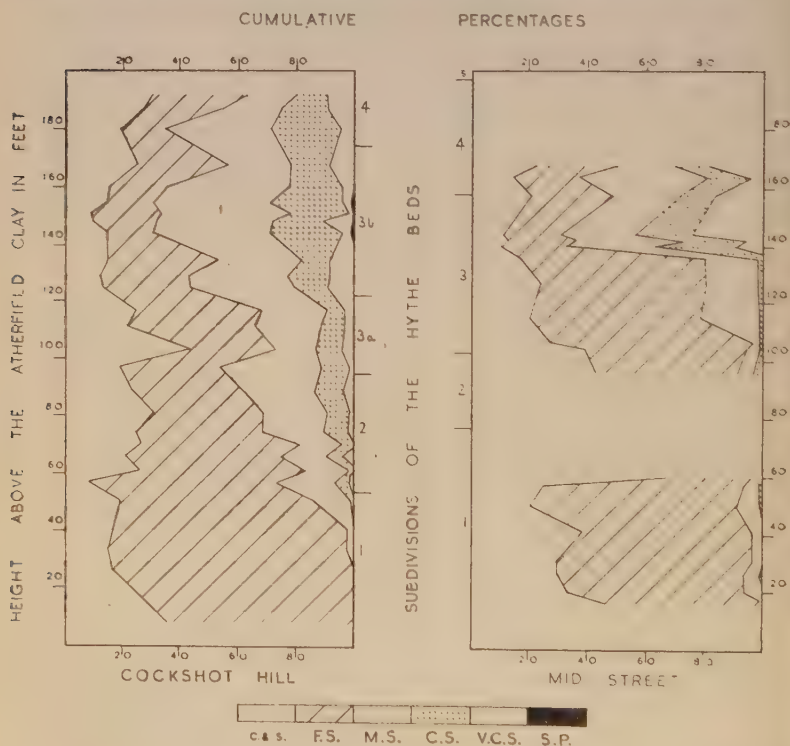


FIG. 13.—EXAMPLES OF THE VARIATION IN MECHANICAL COMPOSITION OF THE HYTHE BEDS.

S.P.	...	Small Pebbles.	Diameter	>2.0mm.
V.C.S.	...	Very Coarse Sand	"	2.0—1.0mm.
C.S.	...	Coarse Sand	"	1.0—0.5mm.
M.S.	...	Medium Sand	"	0.5—0.25mm.
F.S.	...	Fine Sand	"	0.25—0.1mm.
c. & s.	...	Clay and Silt	"	<0.1mm.

he preferred to regard it as the topmost member (Bed 5) of the Hythe Beds. It is, of course, possible that it may be present in the unexposed top 8ft. at Bell Street.

For the next $3\frac{1}{2}$ miles eastwards there were numerous good sections down the face of the escarpment formed by the Hythe Beds. That at Midstreet, Nutfield (305504) has been already published [2, p. 363] and the variations in grading of part of the section are shown in Fig. 13. Examination of Fig. 13 will show that the middle part of the Hythe Beds is distinctly finer in grade than at Bell Street. Gossling had measured up all these sections in detail, using an auger extensively on the poorly exposed portions and he had succeeded in tracing through them the five local subdivisions noted at Redstone Hill. To give two examples, for Outwood Lane (326503) leading south from Blechingley, his manuscript notes are as follows :

Bed 5.	Top Hythe "Stone."				
	Glauconitic more or less silicified sandstone with harder cherty bands and a hard crystalline limestone layer. <i>Geodites</i> common	...	...	at least	16ft.
Bed 4.	Upper Hythe Pebble Bed.				
	Greensand with pebbles	...	...	}	100ft.
Bed 3.	Middle Hythe Sands.	...	...		
	Dark buff coarse and very coarse sands	...	...		
Bed 2.	Lower Hythe "Stone"	...	...	...	25ft.
Bed 1.	Lower Hythe Fine Sand	...	...	...	45ft.
					186ft.

At Mitcheners Bank (338501) by Coldharbour Farm he recorded (condensed):

Bed 5.	Top Hythe "Stone" and Chert Beds	...	...	13½ft.
Bed 4.	Upper Hythe Pebble Bed.			
	Grey greensand with small pebbles and grit	...	...	18ft.
Bed 3.	Middle Hythe Sands.			
	Green coarse sand passing downwards through current bedded sand into pale coloured fine sands	...	...	61ft.
Bed 2.	Lower Hythe "Stone,"			
	set in greyish fine sand	...	...	35ft.
Bed 1.	Lower Hythe Fine Sand	...	...	? 45ft.
				172½ft.

It must be emphasised that the terms "Top Hythe Stone," "Lower Hythe Stone," etc., were used by Gossling for convenience in referring to the different subdivisions noted in the area in which he was working. They were intended to be of local application only, but as this point has already been misunderstood once [9], it is perhaps wiser to use the noncommittal terms of "Bed 5," etc.

When these successions are compared with those already given for the Redhill and Reigate areas it will be noted that Bed 1 persists with great lithological uniformity. The thin development of Stone noted in Bed 2 at Reigate has thickened markedly eastwards and

east of Redhill a lower unit of cemented beds is traceable. Bed 3 is the most variable of the subdivisions, owing partly to the colour changes produced by the different stages of oxidation of the abundant glauconite. It is overlain by a very distinctive unit Bed 4, which at Redhill underlies 6ft. of silty greensand with flaggy siliceous stone and farther eastwards about 15ft. of cemented beds containing much chert. Chert has long been regarded as a typical feature of the upper part of the Hythe Beds of the Godstone and Limpsfield areas, and it was because of this relationship that Gossling preferred to group Bed 5 with the Hythe Beds.

In a manuscript note dated 1933, Gossling summarised the differences between thin sections of the Top and the Lower Hythe "Stone" as follows : "(i) general finer grade of the Lower "Stone" (which is obvious in hand specimens) and (ii) a larger proportion of matrix in the Lower "Stone" : also (iii) the matrix is commonly much finer in the Lower "Stone" and (iv) seems to be composed to a greater degree of isotropic material, also (v) there are no *Geodites* spicules."

These criteria, if reliable, are important ; for from Bower Hill, south-east of Redhill, to Tilburstow Hill, south of Godstone, a chain of outliers occurs at the foot of the Lower Greensand escarpment (see Fig 12). The official view is that they are faulted [8, pp. 11-15] ; but Gossling proved the Bower Hill mass to be the product of landslipping [2] and, as stone beds occur in the other more easterly outliers, it is obvious that means of distinguishing between the Top and the Lower Hythe "Stone" is very germane to their structural interpretation.

Changes in this lithological sequence are foreshadowed in Gossling's manuscript notes of the succession south of Godstone, based on the exposures on Tilburstow Common (354504) and the fine section visible, supplemented by deep auger borings, at Taylor's Hill pit on the Godstone-Blindley Heath road (358507). The succession (slightly condensed) reads as follows :

Bed 5.	Top Hythe Chert Bed.			
	Massive development of chert in the upper, more lenticular development in the lower part	...	...	34ft.
Bed 4.	Upper Hythe Pebble Bed.			
	Yellow coarse sand with small pebbles	...	...	4½ft.
Bed 3.	Mid Hythe Sand.			
	Fine to medium sands, glauconitic, with much curvilinear ironstone and often current-bedded	...	...	72ft.
	(For list of fossils see 5, pp. 326-7).			
Bed 2.	Lower Hythe "Stone."			
	Reddish brown sand containing layers of soft stone			45ft.
Bed 1.	Greyish Lower Hythe Fine Sands	...	...	10ft.
				165½ft.

Bed 4 was clearly on the point of disappearing as a recognisable unit, whilst Bed 2 contained little cemented material. *Chelonicer*

sp. cf. *cornelianum* (d'Orb) and *Tropaeum* cf. *hillsi* (Sow) have been recorded from Bed 2, though their precise locality is not given.

Unfortunately, Gossling did not pursue the detailed investigation of the Hythe Beds east of this point, though he mapped the limits of their outcrop to beyond Westerham.

(c) Sandgate Beds.

The account of the Sandgate Beds in the 1929 paper [1, pp. 226–233] was noteworthy on two accounts. First, skilful and pertinacious use of the auger had shown that they could be traced as a mappable unit from Reigate to Brockham, and that they did not thin out here as the original surveyors had supposed [11, p. 133]. Secondly, the clear description of their eastward thickening and change of facies from glauconitic silts into alternations of seams of Fuller's Earth and calcareo-siliceous stone.

Although he mapped their outcrop eastwards for another 10 miles to the south of Westerham, Gossling has left little descriptive material, except for details of a few sections, as to the lithological characters and variation of the beds. Fortunately an excellent account of the Nutfield Fuller's Earth Beds of the greater part of this area is available in the official memoir [8, pp. 59–65].

(d) Folkestone Beds.

In his 1929 paper Gossling recognised the following local succession :

Upper Pebbly Sands.

Coarse to very coarse, light and dark coloured sands, very regularly current-bedded and with numerous pebbles of quartz, lydite, etc. 50–60ft.

Clay Band.

Variegated glauconitic silts passing downwards into ill-graded silts and fine sands c. 10ft.

Silver Sands.

Fine to medium pale coloured sands with aeolian type of current bedding and a high proportion of rounded and polished sand grains 100–120ft.

Basal Pebbly Sands.

Coarse buff sands with pebbles of quartz and larger pebbles of lydite and siltstone 10–20ft.

The Clay Band proved to be a most useful local datum, which was mapped from $\frac{3}{4}$ mile north of Brockham (190506) for four miles eastwards to the northern part of Redhill (276508), beyond which the "solid" geology is hidden beneath an extensive area of brick-earth.

Farther eastwards at about the same horizon, Gossling has traced another useful local datum, the Silt Band. This consists of some eight to 18ft. of greyish or buff, nearly pure quartz silt, singularly well graded with usually 90 to 95 per cent of the coarse silt

fraction. To the touch it feels like soft flour. Unfortunately the precise relation of the Clay Band to the Silt Band could not be determined, owing to the difficulty of penetrating the sheet of brickearth around South Merstham (290520). Gossling was inclined to think that the Silt Band was a slightly coarser facies of the Clay Band, but the writer considers it more likely that they are two separate lenticles, with the Silt Band at a slightly lower stratigraphical level. One rather significant difference is the virtual absence of glauconite from the Silt Band, but against this might be set the fact that in both bands black specks on the quartz grains are abundant and fragments of black fibrous wood more or less common.

Be that as it may, the Clay-Silt Band horizon proved very valuable in enabling the Folkestone Beds of this area to be divided into an upper and a lower portion. The outcrop of the Clay-Silt Band horizon is shown, partly as a tentative line, on Fig. 12 and below is given an account of the evidence by which this line was traced to the east of Redhill.

The Silt Band is well exposed today in the large sandpits to the west of Pendell Court, Nutfield (314522). Here it consists of 15ft. of buff to lilac-coloured massively bedded silt occurring about 6ft. above the conspicuous dark coloured seam running across the face of the partly abandoned southern workings. Unfortunately it was very difficult to trace westwards towards Redhill, but pale-coloured silts recorded by Mercers Farm (303519) and from a manhole near Ford Bridge (295517) were regarded as being points on its outcrop. Eastwards from Pendell Court the distinctive silt was noted by Brewerstreet Farm (325519) and from there its outcrop is marked by a tentative line on Gossling's manuscript maps, for the fields are smeared over with flinty downwash from the Chalk escarpment. For the next $6\frac{1}{2}$ miles to the east of Godstone, however, there is abundant evidence for tracing the Silt Band. It is typically developed in the lane just north of Godstone Church (356516), where it was noted by the Survey as "unusually fine-grained sand" [8, p. 78] and in the road cutting just east of Nagshall Farm (364517). It can then be followed across the fields to the Priory Pit, Oxted (377525) and through the grounds of Barrowgreen House to Sandy Lane, Oxted, which it crosses just south of White Cottage (384526). It was observed in temporary sections by New Oxted Church (390529), in Bluehouse Lane (396531) and at point 400532. The outcrop then swings round the valley of the small brook towards Limpsfield Common, the Silt Band being exposed in the old sandpit by the Lord Rodney Inn (407528). Temporary sections near the Clubhouse (428536) enabled the Silt Band to be traced to the Birches (424533), in the area covered by Fig. 14 of the succeeding paper [10, p. 197]. Eastwards of the excellent exposures

near Moorhouse, the Silt Band has been mapped to the northern part of Westerham and was still quite typically developed at the most easterly point noted by Gossling. Good exposures were recorded, amongst other localities, in the track leading up to Farley Common (438539), in temporary sections by Buckham Thorns (444543) and in the overgrown sandpit behind the hotel opposite Westerham Station (446545).

The beds above and below the Clay-Silt Band horizon show considerable lateral variation when traced along the strike. In the Reigate-Redhill area, the lower part of the Folkestone Beds consists of a thick development of Silver Sands underlain by 10–20ft. of ill-graded buff-coloured sands with scattered pebbles. This basal pebbly facies, which is a useful mapping horizon, persists eastwards to Moorhouse and at the same time the thickness of sands, in which pebbles occur, increases to about 50ft. The overlying Silver Sand facies is well developed at Pendell Court pit (314522), but does not there, as farther west, directly underlie the Silt Band, being separated from it by 12 to 15ft. of singularly ill-graded coarse sand with scattered pebbles and numerous lenticles of clayey silt. Farther eastwards around Godstone the whole of the lower part of the Folkestone Beds appears to be composed of very ill-graded sands, mainly coarse and with scatterings of pebbles, especially in the lowest beds. Around Oxted, however, the beds beneath the Silt Band become finer and better graded. At Sandy Lane, Oxted (384528) some 40 to 50ft. of bright buff-coloured medium to fine sands separate the Silt Band from the Basal Pebbly Sands, whilst beyond Limpsfield in the roadside pit by the Grasshopper Inn [427534, and see 10, p. 197], the return to the Silver Sand facies is complete.

The often ill-graded and coarse sands with scattered pebbles, which compose the upper part of the Folkestone Beds of the Reigate neighbourhood, continue eastwards to the Pendell Court pit (314522), where they are well exposed in the upper workings. Farther eastwards, however, there is a change. Around Godstone and Oxted the Silt Band is overlain by beds of the Silver Sand facies, well exposed in the pits south of Tylers Green, Godstone (348520) and in the Priory Pit, Oxted (377525). In the Godstone neighbourhood these Silver Sands are separated from the Gault by some 15ft. of coarse pebbly sands, but at the Priory Pit, Oxted, the pebbly development is restricted to the highest 5ft. of the Folkestone Beds. Farther eastwards the whole of the upper part of the Folkestone Beds becomes coarser in grade and not of the Silver Sand type. Remarkably white and clean coarse sands with scattered pebbles and pebbly seams are exposed in Westwood's and Squerrye's big pits (427537 and 431539), to the north of Moorhouse Bank. Full details of these sections will be found in the succeeding paper [10].

IV. THE CONDITIONS OF DEPOSITION OF THE BEDS

In his 1929 paper Gossling summarised the views he then held as to the conditions of sedimentation [1, pp. 255-57], and his subsequent work appears to have caused little modification of the general picture.

The marked increase in coarseness of the upper part of the Folkestone Beds to the east of Limpsfield was regarded as showing that the material was derived from an easterly direction. He was always very impressed by the large number of aeolian-like sand grains in the Silver Sand facies of the Folkestone Beds and latterly he had detected similar grains in considerable numbers in the upper part of the Hythe Beds. In describing the Silt Band at Oxted he wrote, "The uniformity of grade of the silt and the roundness of the grains, it was suggested, indicate a derived aeolian origin, either from dust storms or, less directly, from the sorting of coastal dunes by wave action" [5, p. 323].

The following notes, dated 1944, describe detailed observations of the Hythe Beds of Redstone Hollow, Redhill (284497) :

The general aspect of the section is that of a massive deposit of sand showing only obscure signs of bedding, such as bands of lighter and darker colour, apparently due mainly to the degree of moisture retained. Thin lenticles, very impersistent, of grey clay occur at various horizons.

The sand, except in the upper part, is a *fine sand* with about 14 per cent of medium and coarse silt and 17 to 18 per cent of fine silt and clay. The upper part of the sand contains less clay and silt and some medium and coarse sand. The lower part is glauconitic, but the upper part shows only a trace of glauconite.

The clay occurs in the coherent sand and in rare impersistent lenticles or seams which may run to several feet in length and reach 1in. or more in thickness. But it occurs chiefly in more or less intimate mixture with the sand forming a weak cementing agent. It is also present rather rarely in the form of balls or nodular lumps up to $\frac{3}{4}$ in. across, and rather commonly as small lenticles up to 1in. or more in length and $\frac{1}{16}$ in. to $\frac{1}{4}$ in. or $\frac{3}{8}$ in. thick, these latter lenticles being frequently more or less curved. In all these forms the surface is coated with firmly adherent grains of sand (and glauconite). The balls, etc., are fragile in the dry state and readily break up into fragments of irregular shapes with, commonly, sharp edges, these surfaces being more or less curved or conchoidal. This explains the frequent occurrence in a sample of sand in the loose form of small chunky fragments of clay with clean faces and sharp edges. It is only by carefully extracting the ball, etc., and cautiously removing the enclosing sand that the original shape can be determined, the tendency to break up being so marked. Some of the original balls are, however, very small—about $\frac{1}{4}$ in. across or less.

The following conclusions can be drawn from these observations, viz. :—

- (i) Clay in fine suspension was deposited concurrently with the fine sand.
- (ii) Clay in a pure state which in some way had been coagulated into small balls or lumps, or had been eroded from

previously deposited clay, was deposited along with the usual mixture of clay and fine sand.

- (iii) Clay in a state of purity was deposited *in situ* in small sheets and lenticles. This form presupposes temporary but complete cessation of the deposition of sand.
- (iv) The glauconite, which diminishes in quantity in the upper part, appears to be derived.
- (v) The roundness of the quartz (and glauconite) grains is remarkable especially in the upper part: it suggests at least a sand dune origin.

He had also made a detailed examination of the white matrix of Bed 4, the Top Hythe Pebble Bed. He concluded that "this is a silica residue due to the decomposition of sponge spicules by solution of soluble silica; or it may possibly be a precipitate of silica from solution." Careful examination of Bed 4 in Bowerhill Lane, Nutfield (298496) showed that "a seam consists to the extent of 20-30 per cent of fragments of hexactinellid sponge spicules with some lithistids," whilst at Mid Street, Nutfield (305504) "a seam of fine sand over the pebbly beds is composed of spicules or sponge debris to the extent of 40 per cent."

Gossling's notebooks contain references to several other investigations, unfortunately unfinished, of the minor lithological features of the Lower Greensand. We can paint a broad picture of the conditions under which the Lower Greensand was deposited, but much of the detail is blurred. It will only become sharp and clear by means of careful and painstaking studies of the significance of slight lithological variants; a type of work in which Gossling excelled.

V. ACKNOWLEDGMENTS

The writer offers his best thanks to Mr. B. S. Gossling and Dr. A. J. Bull for their great help in the considerable task of reviewing the late Mr. F. Gossling's geological material and removing that portion useful to the Weald Research Committee to King's College, London; also to these gentlemen and the other members of the Weald Research Committee who have read and commented upon the typescript.

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REPORT OF FIELD MEETING AT REIGATE

By J. F. KIRKALDY, D.Sc., F.G.S.

Saturday, 28th September, 1946

NEARLY 40 members and friends assembled at Reigate Station and then walked northwards to Colley Hill. The weather, though a great improvement on what one had become accustomed to during one of the coldest and wettest summers on record, disappointed in one respect; haze reduced the visibility to about three miles. From a vantage point on the lower slopes of the hill, the Director pointed out those features that were visible and, in outlining the day's programme, spoke of the work of the late Mr. Gossling. After a somewhat slippery descent, during which one member of the party, at least, demonstrated how treacherous wet Chalk can be, the Pilgrims' Way was reached. This was followed to the works of the Reigate Hearthstone Mine in the Upper Greensand. Time did not permit of exploring the underground workings, but the heaps of roofstone were vigorously, though unsuccessfully, hammered. The party then continued along the Pilgrims' Way and, on reaching a bridle path leading south, proceeded to walk "up dip" across the basset edges of the strata. The bench formed by the Upper Greensand was very clearly seen in profile and there was little doubt when the outcrop of the Gault was crossed. Continuing past Colleyhouse Farm, the extensive workings of the Buckland Sand and Silica Co. were reached. Here the Director spoke, at some length, on the detailed lithology of the Folkestone Beds between Brockham and Westerham and the members then examined the following descending succession: Basal beds of the Gault, Upper Pebbly Sands, Clay Band, Silver Sands. The Director stated that, although he had found *Douveilleicerias mammillatum* here in the past, he regarded this section of the basal Gault as exceptionally unfossiliferous. Unfortunately it lived up to its reputation,

and, although the phosphatic nodules were both plentiful and easily accessible, no identifiable specimens were forthcoming. Owing, probably, to the unaccustomed sensation of a temperature of nearly 80°F., the party showed no great tendency to tarry, but adjourned to the 'Black Horse' at the corner of Reigate Heath.

Fortified by a surprisingly varied and plentiful supply of liquid refreshment, the party continued the traverse of the Lower Greensand, by following very pleasant footpaths leading south-westwards across the outcrop of the Silver Sands, to Trumpets Hill. Here rather poor roadside exposures afforded a glimpse of the Lower Pebbly Sands of the Folkestone Beds. The scarp face of the Hythe Beds was then descended and the Director, by contrasting its height with Blackdown, Leith Hill, etc., pointed out the lack of hard bands in the Hythe Beds between Brockham and Redhill. Only in east Sussex, where the beds are much thinner, was the feature formed by the Lower Greensand so low. Returning to the top of the scarp, pleasant footpaths were taken to Park Lane at the western end of Reigate Park. After a short disquisition on the variations in thickness and lithology of the Sandgate Beds, the party spent some time in examining this excellent section of Sandgate Beds resting on the pebble bed, which here forms the top of the Hythe Beds. Owing to the difficulties of post-war catering, tea had to be taken early, but on so humid a day this was perhaps an advantage.

After tea the party walked along the northern side of Reigate Park, keeping very closely to the junction of the Folkestone and the Sandgate Beds, to Cockshot Hill. Hall's (formerly Barnard's pit) was entered and the Director there dealt with the detailed lithology of the Hythe Beds. Dr. A. J. Bull then followed and whilst proposing the customary vote of thanks, paid a warm tribute to the late Mr. F. Gossling. The Director, in his reply, expressed his great admiration of Mr. Gossling's work and also thanked Dr. G. W. Himus, who had carried out the duties of Field Meeting Secretary with his customary efficiency. The examination of an almost complete section through the Hythe Beds (see p. 183) was completed by a visit to Lavender's pit. The majority of the party then returned to the station, but a few enthusiasts accompanied the Director to Woodhatch Brickyard. As they had been warned, this was in very poor condition, long abandoned, thoroughly degraded and with a tip heap spreading ominously across the workings. Typical Weald Clay and typical Atherfield Clay could be easily examined, but prolonged search was necessary to find even the smallest fragments of the fossiliferous nodules for which this section used to be famous.

STUDIES OF PEBBLES FROM THE LOWER CRETACEOUS ROCKS

(Weald Research Committee Report No. 37)

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A Study of the Pebble Beds in the Lower Greensand in East Surrey and West Kent

By A. K. WELLS, D.Sc. and F. GOSSLING, B.Sc., F.G.S., F.C.S.

I. INTRODUCTION

DURING the examination of the Lower Greensand of West Kent and East Surrey the senior author made extensive collections of pebbles from the pebble beds that occur at different horizons. Over a period of 20 years very large numbers of pebbles, running into tens of thousands, had been accumulated, but it was not until 1935 that serious work was done on them. In that year the other author (A. K. W.) examined a collection from certain pits in the Folkestone Beds at Oxted which had been recently visited by the Association under the guidance of Mr. Gossling. The results proved so interesting that it was decided to pursue the investigation further, and much of the material was handed over to A. K. W. for petrographical examination. Brief reference to the preliminary results have been made in the reports on two Field Meetings [16*] and [17].

Previous workers on the Lower Greensand of the Weald, whilst often recording the presence of pebbles, do not appear to have critically examined them, and most references mention only quartz and "lydite" pebbles; this is so, for example, in the Memoirs of the Geological Survey relating to the country around Reigate [13] and around Dartford [10]. A greater variety is recorded in the Aldershot and Guildford Memoir [12] and in the publications of J. F. Kirkaldy [27].

There is clearly scope for fuller records and more complete descriptions. The majority of the pebbles present in the Lower

* For list of References see p. 239.

Greensand on the northern side of the Weald must have been derived in large measure from the concealed Palaeozoic Platform which formed the nearest landmass at the time when the beds were being deposited. From the deep borings a considerable amount of evidence has accumulated as to the age of the rocks which form the Platform, but information as to their petrological characters is surprisingly meagre. Obviously further details should be made available by the study of the products of the erosion of the Platform. Thus the aim of the research was two-fold: firstly, to give detailed information regarding the petrological character of the pebbles; and secondly, to obtain information as to the nature of the rocks comprising the London Platform, and contributing to the formation of the Lower Greensand. The investigation was continued without interruption until 1939, when a joint paper was read to the Association; but publication was postponed indefinitely at the outbreak of war. Before the threads could be picked up again the senior author died. The preparation of an account of the stratigraphical work of our friend by Dr. J. F. Kirkaldy seemed to provide a favourable opportunity for completing the work, started so long ago. In the main the present paper is based on that read to the Association, but the introductory part has been condensed, with Dr. Kirkaldy's assistance.

II. THE HORIZONS OF THE PEBBLE BEDS

The detailed succession of the Lower Greensand between Brockham, Surrey and Westerham, Kent, is stated in the preceding paper, p. 178, and is summarised in Plate 6. It will be seen that pebbly horizons occur in the three divisions:

3. Upper Folkestone Sands.
2. Lower Folkestone Sands.
1. Upper Hythe Beds. (Bed 4.)

1. The Upper Hythe Beds.

In the Hythe Beds the pebbly bands occur in the uppermost 20 to 30ft., comprising Bed 4. Essentially this is a distinctive pebble bed rich in dark "lydites" and vein-quartz pebbles embedded in a white silty matrix. Collections were made at several points between Betchworth and Godstone. In addition, the upper part of Bed 3 has yielded pebbles in smaller numbers at several localities.

2. Lower Folkestone Beds.

Pebbles are consistently largest and most numerous in the basal 20 to 30ft., but in the neighbourhood of Nutfield and Godstone they occur in other horizons as well (see Plate 6). Collections have been made in the basal beds formerly exposed in the pit north of Bramble Wood, Brockham (201504), at Wonham Hill, near

Betchworth (223501) and a pit, now filled in, on the Westerham road south-east of Oxted Station (397527). In this section Gossling recorded some 20ft. of reddish and buff-coloured sands resting on the higher part of the Sandgate Beds consisting of a few feet of red to grey loamy sand containing 20 to 30 per cent of glauconite. In the Lower Folkestone Beds here the basal one to 2ft., and the uppermost 6ft. consisted of very coarse sand, red, brown or buff in colour, containing pebbles up to an inch in diameter. The sand between these two horizons was current bedded, much finer grained, and contained fewer and smaller pebbles.

3. Upper Folkestone Beds.

The most extensive collections of pebbles have been obtained from a conspicuous seam, the "6-inch pebble-bed" which is extremely well exposed in extensive sections in sand pits near Moorhouse (Fig. 14) belonging to the Titsey Estate Company (Westwood's Pit, 427537) and the neighbouring Squerrye's Pit, formerly Covers Brickworks (431539). The horizon is best defined in relation to the Silt Band, which on account of its lithological distinctiveness and persistence as a datum-line, is taken as separating the Upper from the Lower Folkestone Beds. The Pebble Band occurs approximately 20ft. above the Silt Band, which forms the base of Squerrye's main pit. Above the Silt Band there is a very fine section of some 85ft. of clean coarse sand of remarkable whiteness, except towards the base. The section is capped, with a sharp junction, by the Gault. The Folkestone Beds below the Silt Band are well exposed, to a depth of about 35ft., in the roadside pit by the Grasshopper Inn (427534). Here, as is generally the case throughout the district, the sands below the Silt Band are uniformly fine-grained. The full thickness is not exposed in this pit, but the basal Folkestone Pebbly Sands come in farther to the south, and Gossling considered that hereabouts the Silt Band lies at about the middle of the Folkestone Beds.

In the Westwood's pit the Silt Band is not exposed; but its probable position below the base of the pit is shown in the section, Fig. 15,¹ which extends from the pit by the Grasshopper Inn to the well at the Waterworks north-west of Westwood Farm (425542). In the well-section the Silt Band is believed to be represented by a seam of yellow sand occurring at 85 to 97½ft. down in a total thickness of 21½ft. of Folkestone Sands.

In both Squerrye's and Westwood's pits the Pebble Band exhibits the same characters; it is an irregular and somewhat "pocketty" seam, varying between six and 15in. in thickness, but usually of the order of 6in. The matrix is normally of finer grain than the sand above and below it, and tends to hold up water. In some places there is a sporadic occurrence of smaller pebbles

¹ This section is in part a continuation to the northward of that given in 2, p. 343.

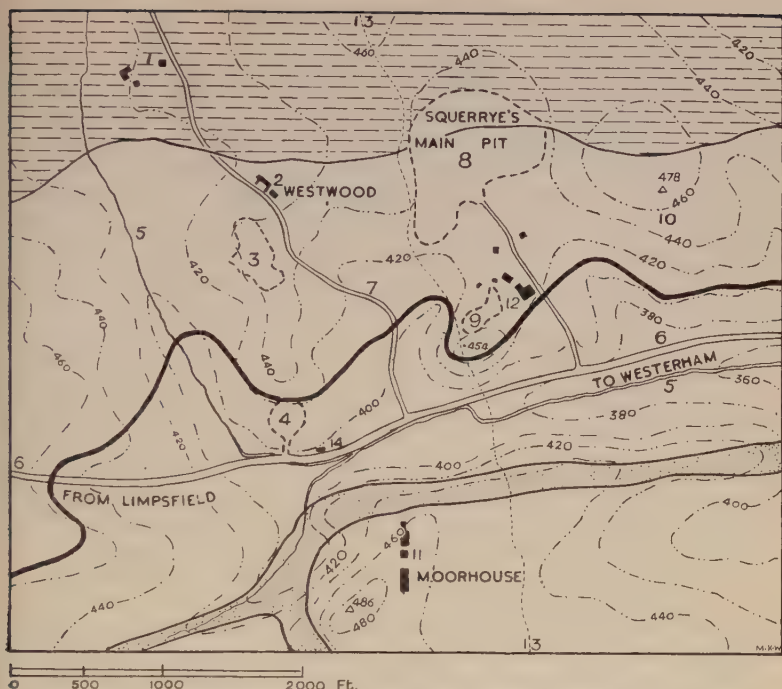


FIG. 14.—GEOLOGICAL MAP OF THE AREA AROUND WESTWOOD'S AND SQUERRYE'S PITS.

Horizontal Ruling ... Gault.

White Folkestone Beds, with Silt Band shown as thick line.

Stippled Sandgate Beds.

- | | |
|------------------------------------|----------------------------------|
| 1. Westwood Pumping Station. | 8. Squerrye's main pit. |
| 2. Westwood Farm. | 9. Squerrye's old pits. |
| 3. Westwood's main pit. | 10. Farley Common. |
| 4. Westwood's roadside pit. | 11. Moor House. |
| 5. River Darent. | 12. Covers Farm. |
| 6. Limpsfield-Westerham main road. | 13. Kent-Surrey County Boundary. |
| 7. Clackett Lane. | 14. Grasshopper Inn. |

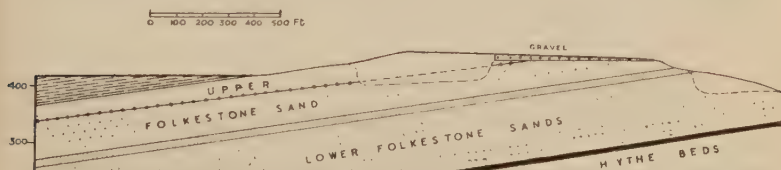


FIG. 15.—Section from Limpsfield main road (Pit 4 on Fig. 14 above) through Pit 3 to the waterworks near Westwood's Farm (1). The beaded line is the 6in. Pebble Band; the finely stippled bed is the Silt Band in the Folkestone Beds, and the Sandgate Beds are shown in solid black.

in the sand for a foot or more above the 6in. Pebble Band. The surface of the sand on which it rests appears to have been irregularly furrowed by current action. The sands above the Pebble Band in both pits show a succession of regularly current-bedded foreset beds, interrupted at intervals by horizontally stratified seams.

Between the Pebble Band and the Silt Band the sands show several features of interest : the top 10 feet are regularly current-bedded and nearly white ; but below this the sand is strongly stained with limonite, and current-bedding is hardly discernable. It is very coarse-grained, often pebbly, and includes a band about 2ft. thick containing many pebbles up to a half-inch or more in diameter. Similarly in Squerrye's pit the section immediately over the Silt Band shows about 16ft. of very coarse, red-brown, pebbly sand, the upper and lower parts of which are current-bedded, while the intermediate portion shows several horizontal seams. The significance of the current bedding is considered below (p. 239). It is noteworthy that there is a difference of 45 degrees in the bearing of the foresets at the Pebble Band : above it the bearing of the direction of dip is 160 degrees ; below it, 218 degrees.

About $3\frac{1}{2}$ miles west of the Moorhouse pits the Folkestone Beds are again exposed in the Priory Pit, Oxted (377525). The Silt Band is seen in the south side of the pit, while approximately 26ft. above it there are three pebbly seams, each a few inches in thickness, in a vertical distance of about 2ft. There can be no doubt that these represent the 6in. Pebble Band of Westwood's pits, though the pebbles are much smaller here, rarely exceeding $\frac{3}{8}$ in. in diameter. Further, the sand below and above the pebbly horizon is much finer grained than at Westwood's, which must obviously have been closer to the source of supply than Oxted was. This indicates derivation from the east or north-east.

In a sand-pit west of Brasted, formerly known as " Ben Smith's Pit " (462547) a pebbly band from six inches to a foot in thickness and with a white clay matrix, sharply separates a fine to medium-grained sand below, from a coarse, pebbly sand above. The horizon of the pebbly band is uncertain, as the Silt Band is not exposed, but on the grounds of lithological similarity there is little doubt that it is approximately on the same horizon as the 6in. Pebble Band at Westwood's and Squerrye's pits.

III. TECHNIQUE

The method usually followed by Gossling was to take a large sample of the sand and separate the pebbles on the spot, using a sieve with 2mm. mesh. They were then roughly sorted and classified prior to detailed examination. Thus, with some exceptions, the collections were suitable for quantitative, as well as qualitative, study. In the big pits in the Upper Folkestone Beds at Moorhouse the sand was screened on a big scale by workmen, and thus large

dumps of pebbles were available for selection. In a few cases the pebbles were hand-picked from the working face of a pit, and only the more interesting specimens were collected.

The laboratory examination of the material has involved the scrutiny of all but the more obvious specimens under the binocular microscope [57]. Specimens which gave promise of proving interesting were ground smooth—polishing is not necessary—and cemented to a glass slip. They were then examined *through* the glass with the binocular microscope, using the strongest possible illumination. Treated in this way, many of the pebbles are sufficiently translucent for their internal structures to be studied in three dimensions. This is a great advantage over a thin section; but, of course, the microscopic characters of the minerals in the rocks could be studied only in thin section. The latter, in considerable numbers, have been prepared for this paper by Mr. A. V. Weatherhead, to whom the authors are grateful for expert assistance in a variety of ways: he has photographed numbers of the pebbles for us, and took the photomicrographs (with one exception) used in illustrating the paper.

IV. THE PEBBLE SUITES

As is already well known, the majority of the pebbles in the Lower Greensand are of vein-quartz and “lydite.” In addition, quartzites, sandstones, arkoses, siltstones, phosphatic and ferruginous rocks and occasional rarer types are also represented.

In the account which follows, the pebble-suites from the three formations are described in general terms, in stratigraphical order. Later sections are devoted to the description of the petrographical characters of the several rock-types represented. Problems of provenance are discussed as they arise.

Originally it was intended to embody a tabulated statement of the results of this investigation; but it now seems pointless. To bring out the salient features of the local variations a number of selected analyses are appended. In these the actual numbers of pebbles examined are stated in a few instances. In order to make comparison easy the numbers have been standardised, vein-quartz in all cases being reduced to 100, and the other types in proportion.

(a) The Hythe Pebbles.

The material was collected from 15 localities, shown on the sketch-map (Fig. 14). From some of them the amount of material was too small to be considered adequate for quantitative study, though interesting specimens were obtained.

Gossling's material from the “Top Hythe” at Park Lane, Reigate (244495), 5ft. below the “stone bands,” was augmented by two samples collected by Dr. Kirkaldy. The pebbles range from 3mm. to about 8mm., and rarely to 12mm., and are embedded in

a medium to very coarse sand matrix. In two of the collections the amounts of vein-quartz and chert are approximately equal; but in the third, vein-quartz is twice as abundant as chert—a curious anomaly, perhaps to be accounted for by the small yield of pebbles—a total of 233 only, from this sample. The most representative sample yielded:—

<i>V-Q.</i> ¹	<i>Ch.</i>	<i>Ph.</i>	<i>Fe.</i>	<i>Qtes.</i>
395	250	60	62	2
= 100	: 62	: 15	: 15	: 0.5

Among the cherts from this locality the majority, as elsewhere, were just cherts with no outstanding features; but the following were obtained: spherulitic chert, spherulitic limonitic chert, oolitic chert, and chert with pseudomorphs after rhombohedral carbonates, two each. These special types are described below.

The matrix from approximately the same horizon at Mid Street, Nutfield, is a glauconitic, limonitic sand, locally cemented by very fine-grained white siliceous clay into soft sandstone, which has to be crushed to set free the pebbles. The yield of pebbles was much greater from a sample of the same bulk than from the Reigate Top Hythe Beds, though many of them were small. In the appended list the numbers of large and small pebbles are stated separately:

	<i>V-Q.</i>	<i>Ch.</i>	<i>Ph.</i>	<i>Fe.</i>	<i>Qtes.</i>
Large	196	70	160	62	—
Small	480	174	265	485	A small number included with V-Q.
Total	676	244	425	547	—
	= 100	: 36	: 63	: 81	—

It will be noted that, while the ratio of chert to vein-quartz is almost identically the same for small, as for large pebbles, the ironstone rises from 31 in the large to 81 in the small, for every 100 vein-quartz. In this suite chert is down by nearly one half as compared with the Reigate suite; but the outstanding feature is the flood of phosphate and ironstone pebbles which rise from a total of 30 per 100 vein-quartz to 144. A second sample from the same locality and approximately the same horizon (the base of Bed 4, the Hythe pebble bed) showed a similar large preponderance of phosphate and ironstone over chert, but both were heavily outnumbered by a flood of small quartzes. Of the latter, 1,525 were counted in a total of 2,050 pebbles. Consequently the ratio of chert to vein-quartz is abnormally low: only 12 of the latter to 100 of the former. It may be noted that Gossling records only 5 per cent cherts among the small pebbles obtained from the *Middle Hythe Beds* of Lavender's Pit, Cockshot Hill (255494) Reigate; at this level also there is a flood of small quartzes.

¹ V-Q. = vein-quartz; Ch. = "lydites" (cherts); Ph. = phosphatic; Fe = ironstones; Qtes. = quartzites and hard sandstones.

Among the varieties from Mid Street, Nutfield, are oolitic chert (3), spherulitic chert (2), micro-agate (1), and a beautiful bright-red jasperised chert containing abundant bryozoa. A single pebble of micaceous sandstone among many hundreds of other types is noteworthy.

The distinctive features of the Upper Hythe pebble-suite are the locally high content of phosphatic and ferruginous pebbles ; the variable ratio of chert to vein-quartz ; the insignificantly small proportion of quartzite, sandstone and micaceous siltstone. In connection with the small number of quartzite pebbles recorded, it should be noted that considerable difficulty was experienced in distinguishing between Hythe quartzites and Hythe vein-quartzes. Both have been severely pounded by wave action, which has had the effect of bruising and chipping the surfaces, rendering them opaque and granular-looking. In many instances distinction was possible only after grinding and mounting the pebbles, or breaking them to expose a freshly fractured surface. It is perhaps worth recording that the majority of the pebbles originally classified as "quartzites" after superficial examination, were subsequently proved to be vein-quartzes. It is possible that we have gone too far in the opposite direction, and under-estimated the quartzites, particularly in the "smalls" ; but making due allowance for this, the fact remains that pebbles of arenaceous sedimentary rock-types and metamorphic quartzites are present, if at all, in only very small numbers. In only two of the collections does the number run into double figures ; in most, they are very rare, in some, absent.

(b) Lower Folkestone Pebbles.

From the Lower Folkestone pebble-beds Gossling made 25 collections from eight different localities ; but again, several of the collections were inadequate for quantitative study, and we propose to concentrate on the material collected from the Oxted and Limpsfield Sand Pit, near Oxted Station. Compared with the Hythe pebble-suite there are some striking contrasts, the most notable feature being the incoming of significant quantities of quartzite, sandstone and particularly siltstone pebbles. Ironstone remains an important constituent, but phosphate is virtually suppressed. An interesting addition to the suite is acid igneous rock, which reaches its maximum concentration for the Lower Greensand on this horizon. Again, to keep the right perspective, it is necessary to record that the rhyolite pebbles identified with certainty from this locality number 16, with double this number "probable." This is almost certainly an under-estimate, as it is impossible to identify this rock-type among the "smalls," for obvious reasons. In the different collections the chief components vary a good deal in their relative proportions : a small suite of 170 pebbles contained a large preponderance of micaceous siltstone pebbles (90), about

equal amounts of vein-quartz and chert (31 each), quartzites (7) and rhyolites (6).

The largest collection from this pit was dealt with in two parts—large pebbles and “smalls.” The large ones, totalling nearly 500 pebbles, included equal numbers of siltstones and vein-quartz (102 and 93 respectively); cherts more abundant than these in the proportion of about 1.5 to 1 (actually 163 specimens, including eight oolitic cherts); quartzite and rhyolite equal (32 each), sandstone and ironstone equal (19 and 21 respectively); phosphates, none. Among the “smalls” the order of importance is vein-quartz (1,431), ironstone (600), siltstone (270), chert (131 only). Bearing in mind the nature of the matrix—it is highly ferruginous very coarse sand—it seems reasonable to infer that the inclusion in the count of smaller and smaller grains must automatically raise the proportion of vein-quartz to the other components—a conclusion already anticipated in the account of the Hythe pebbles. A feature of very special importance is the occurrence of an extraordinarily high proportion of cherts with organic remains. The yield of oolitic cherts is also notably high.

(c) Upper Folkestone Pebbles.

The pebbles to be described were collected from 13 localities, but the greater part of the material available came from Westwood's and Squerrye's pits. Collections under 20 different reference numbers occur among Gossling's material from these two pits; but many of these contain selected pebbles only—not unsorted samples. The quantitative statement is based, therefore, on one large sample, collected just before, and exhibited at, the meeting at which the paper was read. This contains; vein-quartz (561), quartzite (274), sandstone and siltstone (182), chert (148), rhyolite (13), oolitic chert (10). Thus the proportion of vein-quartz to total quartzite, sandstone and siltstone is 100 to 83. This high proportion of arenaceous sedimentary rock-types among the pebbles is the outstanding feature of the Upper Folkestone suite, particularly of the 6in. Pebble Band.¹

A smaller collection from the same horizon in Squerrye's pit contains :—

<i>V-Q.</i>	<i>Ch.</i>	<i>Qtes.</i>	<i>Siltstones.</i>
100	209	63	56

The only noteworthy feature here is the larger content of cherts. This applies also to the pebbly sand immediately above the Silt Band, i.e. to the basal Upper Folkestone Sands, in which both chert and micaceous siltstone are more abundant than vein-quartz. Quartzite appears to be very subordinate at this horizon, but micaceous siltstone is very abundant. As might be expected, these

¹ The sample analysed above came from the 6in. Band in Westwood's Pit.

two pits have yielded numbers of interesting rare types, among which a little-worn pseudomorph in limonite after pyrite, showing the cube-octohedron crystal form, is noteworthy. Tourmalinised rhyolite and tourmalinised killas also appear to be specially significant from the point of view of provenance, but we postpone further consideration for the moment.

For comparison with the Westwood and Squerrye's material we pass to Ben Smith's Pit, Brasted, whence a particularly attractive collection of cherts has been obtained. As a fact, however, there are striking contrasts in the general appearance and mode of preservation of the pebbles, as well as in the proportions, which make one wonder if they are actually, as Gossling believed, on the same horizon. The suite is essentially one of vein-quartz and chert (in the ratio of 100 to 20), with both quartzite and siltstone very subordinate. It must be remembered, however, that we are dealing with much smaller material, and as on the other horizons described above, the inclusion of the "smalls" in the analysis has the effect of unduly emphasising the proportion of vein-quartz, while some quartzites may have been counted in with the quartzes. Even so, the fact remains that among the larger pebbles the proportion of vein-quartz to quartzite and siltstone is 100 to 12 and six respectively. In common with the other Upper Folkestone material, phosphate and ironstone are virtually absent from the Brasted exposure. Special features of the cherts are a large proportion showing organic remains, and many containing pseudomorphs after rhombohedral carbonates. Finally, a collection of some 300 pebbles from the pit in the Upper Folkestone Sands at Buckland (227159) gave an analysis essentially intermediate between those for Brasted and Moorhouse. Here vein-quartz and chert are approximately equal and in excess of combined quartzites, sandstones and siltstones, in the ratio of 100 to 72, siltstone being twice as abundant as quartzite.

V. PETROGRAPHIC CHARACTERS OF THE PEBBLES

(a) The Cherts.

Under this heading we include the pebbles formerly referred to as "lydites," for in our experience these with rare exceptions are cherts—of many different types. Dealing first with their more obvious characters, from the point of view of their colour, cherts fall into four groups. Many, probably the majority, are the well-known blue-black to jet-black pebbles that occur at several levels in the stratigraphical column. Next in order of abundance come limonitic cherts, varying from yellow to brown. They may be uniform in colour, or blotched or streaked with black in irregular fashion. Third in order of abundance are cherts ranging from grey to nearly pure white. Although recorded from all three

horizons, these are distinctly rare in the Upper Hythe and Lower Folkestone pebble beds, but are often dominant among the Upper Folkestone cherts, especially from Westwood's and Squerrye's pits. These are discussed further below. Distinctly rare, though occurring on all three horizons, are jaspers or semi-jaspers, ranging from the typical brilliant red to anaemic pink specimens, occurring fairly plentifully in the Upper Folkestone pebble-beds. The red colour seems to be merely an accident of pigmentation, for the jaspers exhibit the several structural peculiarities of the cherts in the normal groups, and contain the same organic remains as the latter.

Structurally also the cherts are exceedingly variable. The typical blue-black specimens normally show little of interest in thin section: they consist of granulo-chalcedony—a cryptocrystalline aggregate of quartz mosaic. Stratification or lamination is not uncommon; while one Upper Folkestone 11mm. pebble is cleanly sliced across by a miniature normal fault as neatly as in a text-book diagram. Wedge-bedding is less common but is shown by specimens from the Upper Hythe pebble-bed at Tilburstow, and from the Upper Folkestone sands of Squerrye's pit. It may be mentioned that wedge-bedding is characteristic of the Lower Carboniferous chert of S. Wales, and we may perhaps use this trivial feature to illustrate an important point. It would obviously be ludicrous to claim derivation of our pebbles from S. Wales on this slender evidence. The evidence would be acceptable only if it had been proved that the chert of other ages and other localities is never wedge-bedded. Probably the most regular stratification is shown by some of the spicular cherts. Outstanding examples are twin pebbles (20mm.) from the Lower Folkestone sands in the Oxted Station pit. These show blue-grey featureless bands alternating with softer, slightly etched cream layers, composed largely of sponge spicules. These are among the most striking looking of our specimens.

(i) *The Oolitic Cherts.*

It will have been noticed that in the account of the general characters of the pebble-suites, reference has been made to the occurrence of oolitic cherts, of the type commonly called "silicified oolites." They are very widely distributed, though nowhere in large numbers. Some specimens have been collected from all the Folkestone, and all but three of the Hythe, localities; but in this connection it should be remembered that the collections are relatively small, and there is no doubt that further more extensive collecting would bring to light the missing pebbles. No significance therefore attaches to these few gaps in the record. The oolitic cherts are so variable in their individual characters as to make it difficult to believe that they have been derived from one

source only. Actually they are as variable in such characters as colour, lustre, and mode of preservation as the more normal cherts: some are black, others shades of brown, yellow, grey or they may be white. The ooliths may stand out from the surface of the pebble as in weathered oolitic limestone, but they have been etched out, leaving spherical voids in other cases. In some, there is the closest superficial resemblance to oolitic limestone (and a hardness test is called for), but in others, ooliths and matrix are all but identical, and very careful examination is necessary in establishing their identity.

Provenance of the Oolitic Cherts.

Silicified oolitic limestone has been recorded *in situ* by W. J. Arkell [3] from the Portland Stone of the main outcrop in Dorset, where it occurs as lenticles of oolitic chert. Although the cherty facies dies out eastwards, and although recent borings in south-eastern England which have penetrated the Portlandian have not met with Portlandian chert, this horizon remains a likely source of some of our oolitic cherts, particularly the light grey to white ones. Only the discovery of a Portlandian fossil in one of the pebbles would prove the point; but the nearest we have got to this is figured in Pl. 7. This is the largest fragment of oolitic chert so far collected, and shows at one end a fragment of a thick-shelled lamellibranch, possibly an oyster. Of course, not all the Portlandian chert is oolitic, and specimens collected from the upper part of the formation by Gossling for direct comparison very closely resemble some of the Greensand pebbles, matching in colour, texture—they are curiously granular-looking—and even in containing silicified sections of shells, unfortunately not identifiable.

The Corallian formation in Yorkshire is chert-bearing on some horizons, and Vernon Wilson's account and photomicrographs show points of similarity to some of our pebbles [60]. It is probable that some of the so-called oolitic cherts are actually *Rhaxella*-cherts of Corallian age, though not necessarily derived from Yorkshire: they would have had to cross the barrier of the Palaeozoic Platform to reach Surrey and Kent.

The other obvious source is the Lower Carboniferous, which is locally very rich in chert, though records of oolitic chert seem curiously elusive. However, the Ebbsfleet, Kent, boring penetrated silicified oolite in the Carboniferous Limestone, and the general lithological characters of some of our pebbles as well as the details of their mineral composition—admittedly not very strong evidence—leads us to believe that they were drawn from the same province as the fossiliferous cherts, described below, which are of Carboniferous age and Yoredalian facies. It may be noted that Gilligan [15] records pebbles of silicified oolites from the Millstone Grit of the north Midlands. Pre-Carboniferous sources are also available, for

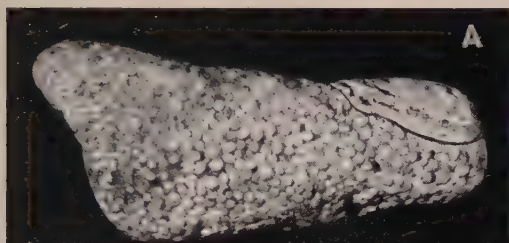
the cherts in the Cambro-Ordovician Durness Limestone are in part oolitic, while even the Torridonian has yielded similar pebbles, though the ultimate source, which must be Pre-cambrian, remains undiscovered [52]. Even this long list may not be exhaustive for Twenhofel, when discussing the origin of such rocks, goes so far as to state that "it is not unlikely that oolites of silica occur in every geologic system, though they appear to be more abundant in the earlier ones." [55].

In view of the occurrence of oolitic chert pebbles in so many pebble-beds on different horizons it becomes extremely difficult to tie down our specimens to one or two definite sources. The problem involves the discussion of the ages of cherts of other kinds, considered below.

(ii) *The Spherulitic and Agate Cherts.*

During the examination of thin sections of the presumed oolitic cherts, some of the pebbles were discovered to exhibit internal structures inconsistent with the mode of origin usually ascribed to oolitic rocks. An ordinary oolite is a self-supporting, close-packed aggregate of spherical to ovoid bodies which grew by accretion about nuclei. This is often beautifully shown by pebble mounts of genuine oolitic cherts, when the orbs, touching one another at points of contact only, are seen suspended in a matrix of chalcedony or quartz-mosaic. In these others, however, the matrix contains aggregates or chains of spheres, imperfect by reason of mutual interference during growth. These are distinguished as true spherulitic cherts. Although rare—not more than a dozen have been collected—they again cover the whole time-range of the rocks under review: they occur in the Upper Hythe pebble beds at Reigate, Redhill, Blechingley and Tilburstow; the Lower Folkestone beds at Oxted and the Upper Folkestone division at Brasted.

The spherulitic cherts belong to a group possessing colloidal characters. The most attractive of these are identical with the agates of mineral collections except for their small size. Micro-agate seems an appropriate term to apply to them. It is surprising how many cherts among our material show agate-structure, though the number of *obvious* specimens is small. Usually the characteristic concentric banding is restricted to perhaps one narrow band in a stratified pebble, or to one small patch in an otherwise uniform, featureless chert, which strongly suggests that if agate-structure is accepted as evidence of a colloidal origin much of the featureless chert has formed from colloidal silica. This is certainly true of the "microchalcedonies," translucent under strong illumination that, like the micro-agates, are widely distributed both as regards localities and horizon. From the point of view of origin it is significant that the matrix in both oolitic and rhomb-bearing cherts occasionally shows local patches of agate-structure.



The largest pebble obtained, superficially resembling an oolitic limestone, in old ivory. Upper Folkestone Beds, Westwood's Pit. ($\times 4$)



Siliceous orbs of two kinds: lustrous brown orbs of chalcedonite; and others, scarcely visible, of quartz mosaic. Upper Hythe Beds, Wonham Hill. ($\times 14$)



A very small pebble of the "micro-agate" type. Black orbs with a white skin, set in a translucent matrix. Windmill Pit, Stone, near Aylesbury. ($\times 20$)

[Photo by A. V. Weatherhead.]

OOLITIC CHERT PEBBLES FROM THE LOWER GREENSAND.

[To face p. 206,

(iii) *Cherts with Organic Remains.*

An unexpectedly large number of chert pebbles containing organic remains have been collected. Although the fossils are seldom specifically identifiable, a microfauna has been obtained that allows definite conclusions to be reached as to the age of some of the rocks from which the pebbles were derived.

As seems appropriate in the Lower Greensand, spicular cherts are more abundant than other fossiliferous types; but although some of the material superficially resembles Lower Greensand chert, much of it is definitely older than this—some pebbles which are intricately quartz-veined are probably Palaeozoic. Dr. K. P. Oakley, who has kindly examined our thin sections of spicular chert, reports that although the spicules in the samples submitted to him are too poorly preserved to be accurately named, from the general aspect of the assemblage he judges it to be of Lower Carboniferous age. One of the pebble mounts of spicular banded chert from the Upper Folkestone 6in. Pebble Band contains spicules showing their solid form, and appear to be *Spiractinella*, a Lower Carboniferous sponge. Any possible doubt is dispersed, however, by the discovery, in one of the thin sections, of immature Lower Carboniferous foraminifera belonging to the genera *Archaeodiscus* and *Endothyra*, associated with sponge spicules.

Even more striking under the binocular microscope are cherts with small crinoid ossicles and fragments of polyzoa, associated with foraminifera. Most of these pebbles are highly polished, of a rather distinctive shade of grey, with the fossils beautifully displayed on the surface. Again specific determination proves impossible; but Dr. Oakley reports the presence of "Fenestellids," and favours derivation from a Carboniferous source.

The foraminifera have proved more useful, and with valuable assistance from Dr. C. D. Ovey the following list has been compiled:—

Archaeodiscus karreri Brady.

Trochammina sp., of Brady.

Valvulina palaeotrochus.

Valvulina palaeotrochus var.

Valvulina sp. identical with one figured from the Carboniferous.¹

Nodosinella sp.

Endothyra radiata Brady.

Endothyra ornata Brady.

Endothyra spp. common as young individuals in some chert pebbles.

There is no doubt that the list could have been enlarged by cutting up the pebbles, but they had already served their purpose,

¹ *Monograph of the Pal. Soc. on the Carboniferous and Permian Foraminifera*, Pl. XII, Fig. 1.

and are more instructive left whole. The best specimen of *Endothyra ornata* Brady in the writer's possession came from the Lower Cretaceous of Stone, near Aylesbury, and therefore outside the district under examination; but it is a particularly beautiful specimen, seen in a horizontal plane section, preserved in white siliceous and embedded in a rich brown chert 3mm. in diameter.¹ It was found in a small collection of selected pebbles from this locality, presented to the authors by Mr. G. M. Davies, to whom they express their thanks. With regard to the age of the foraminifera, with one possible exception (which Dr. Ovey refers to as "an extraordinary fusulinid-like form more advanced than *Stafella*," an Upper Carboniferous form), all these occur in the Lower Carboniferous. Brady notes that *Endothyra ornata* is rare in the English Lower Carboniferous and less rare in the Upper division.

Confirmation of this evidence of the age of these cherts is superfluous, but it is provided by the presence of sections through young individuals of the characteristic Carboniferous gasteropod, *Euomphalus*, displayed on the surface of another grey chert pebble. The general facies of the fauna is Yoredalian. The significance of this conclusion is discussed below.

With regard to the distribution of the fossiliferous cherts, the 20 specimens collected came from nine different localities; one in the top Hythe beds and four each in the Lower and Upper Folkestone beds. Although the pebbles are normally grey, almost pure white specimens have been collected from Westwood's Pit (Upper Folkestone), while a brilliant red jasper from Mid Street, Nutfield (Upper Hythe) contains the same fossil assemblage.

(iv) *The Rhomb-bearing Cherts.*

One of the more interesting results of the study of the Lower Greensand pebbles has been the discovery that a relatively large number contain rhombohedral crystals. It is significant that the latter occur in cherts covering the whole colour-range, and even sporadically in the special types—the oolitic and spherulitic cherts and the micro-agates. They occur in every representative collection, usually in small numbers, from all three horizons. In the Hythe pebble beds they average about 10 per cent, but rise to 24 per cent of the total cherts from Redstone Hill, Redhill. The largest "bag" of this type is 31 pebbles from the Upper Folkestone beds at Ben Smith's pit. In most instances identification was possible only after careful scrutiny under the binocular microscope; indeed, some are singularly attractive objects when examined in this way, for the perfectly formed little sharp-edged rombs appear suspended in a translucent siliceous matrix. In other cases the matrix is opaque, but the crystals are seen in section on the surface

¹ The extraordinary good fortune of a perfect central section of this small foraminifer being discovered in so small a pebble will be appreciated.

of the pebble, and are quite distinctive. Again, in some instances the rhombs have been removed in solution, and empty, sharply polygonal cavities are seen at the surface. As they are presumably unfamiliar to students of the Greensand, a fuller description is perhaps justified. Any pebble which has a pitted surface should be carefully examined, and in many cases the tell-tale polygonal cavities will be seen. Apart from these, however, there are many which are less obvious. For example, an Upper Folkestone specimen from Ben Smith's pit, Brasted, to the naked eye looks like an ordinary rusty brown chert with resinous lustre, but with the binocular microscope the surface is seen to be studded with small lustrous rhombs ground flat with the surface. Another from the same horizon is apparently just a dull brown chert, but suitable magnification resolves it into a shining black chert resembling obsidian in appearance, crowded with minute ferruginous rhombs. Often the rhombs stand in strong relief against a differently coloured matrix, but this effect is only skin deep, and beneath the surface there may be only the slightest difference between matrix and crystals, indeed, in some instances the latter merge so perfectly into their background as to be virtually invisible.

Apart from their petrographical characters, we are concerned with the provenance of the pebbles. Our first reaction to the discovery of this type among our pebbles was to regard them as silicified dolomites; that is, as limestones in which replacement of calcite (or aragonite) had been arrested at an early stage by silicification. This is in line with the views expressed by Black, Hatch and Rastall, who describe and figure a chert containing dolomite rhombs from the Lower Palaeozoic Durness Limestone of the N.-W. Highlands [19, Fig. 52]. In a series of three papers dealing with the cherts in the Carboniferous rocks of N. Wales, Yorkshire and Derbyshire, Sargent [46, 47, 48] notes the local abundance of "rhombohedral crystals assumed to be dolomite," accompanied by fewer ferruginous rhombs which H. H. Thomas suggested might be ferriferous dolomite or siderite. Thomas himself had previously noted small dolomite rhombs and larger opaque crystals of ferriferous dolomite or siderite in the Millstone Grit cherts in S. Wales. The account of the cherts and agates in the Lower Carboniferous of Derbyshire by P. Jessop [22] contains a record of cherts which, judging from the description, must be at least superficially very similar to the pebbles under discussion.

There are also certain foreign records which are germane to the present discussion. We may note a very full, though early account of rhomb-bearing "phthanites" (cherts) from the Lower Carboniferous of Belgium [45]. This account is illustrated by a figure which might well have been made from our material. Similarly,

L. Cayeux, in his account of the siliceous rocks of France, described certain Precambrian phthanites from Brittany, which contain rhombohedra of calcite accompanied by ferruginous crystals of the same form, and in other instances by mixed crystals, partly calcite, partly iron, there being all gradations between the two carbonate minerals. Very similar rhomb-bearing cherts are described by Cayeux from the Lower Carboniferous rocks of northern France, and he regards the numerous perfect unit rhombs as specially characteristic of the Carboniferous "silexites"—cherts free from globular or other forms of opal [9, p. 364.]

Thus rhomb-bearing cherts are known to occur in the Durness Limestone and in the Lower Carboniferous of N. and S. Wales, the northern English Midlands, Belgium, and northern France, in the Precambrian of Brittany and the Millstone Grit of S. Wales. We have examined the specimens and thin sections in the Geological Survey collection and find little in common with our specimens. In particular, the South Welsh rocks contain organic remains, much residual calcite and many detrital grains which are completely absent from the Lower Greensand pebbles. Further, the rhombs are far fewer in number and of much larger size. There are no essential differences, however, between our pebbles and the cherts in the other localities named, except for this one significant contrast: in none of the pebbles we have so far sliced is there a single rhomb of carbonate—they are all pseudomorphs, usually highly siliceous. None of the British records that we have consulted contains any reference to silicification of the rhombs, but Cayeux observed that, although silicification of the rhombs in the Precambrian phthanites is a rare phenomenon, crystals have been observed that resolve themselves into aggregates of little granules of quartz. Similarly, some rhombs in the Carboniferous silexites are very occasionally "quartzified," and "must be susceptible to complete replacement." This would imply that the Yoredalian cherts in the north Midlands may well exhibit this replacement in outcrops not yet examined. However, it remains true that, so far as we know, the rhomb-bearing chert-pebbles in the Lower Greensand cannot be *exactly* matched in any British area, but are extraordinarily similar to the Precambrian phthanites of Brittany and the Carboniferous silexites of northern France and Belgium. The petrographical evidence will carry us no farther; but the microfauna in certain of the other chert pebbles proves derivation from Carboniferous source-rocks. Further, the occurrence of rare rhombs in the crinoidal and bryozoan chert pebbles favours the Carboniferous, rather than the Precambrian source. This of minor importance, however, compared with the legitimate conclusion that the material was derived from Armorica. We wish to make it quite clear that this must not be taken to mean direct derivation from the existing outcrops; judging from the direction of the current bedding in the

Lower Greensand it is likely that the source-rock is buried under the Mesozoic rocks of south-eastern England. The possibility of this is discussed fully in a later section by Dr. Kirkaldy.

We propose at this stage to examine the validity of the evidence on which conclusions similar to that just reached are based. In the course of this work the writer has come to appreciate the serious limitations of attempting correlation on the evidence of mere petrographical similarity. The value of such evidence is directly proportional to the rarity of the rock-type concerned. It may be laid down as axiomatic that with such common and widely distributed rock-types as quartzites, sandstones and cherts, it is not sufficient to demonstrate that a certain pebble resembles, however closely, a known source-rock, but that it is dissimilar from all others of the same type. In the writer's opinion this calls for a far greater detailed knowledge of the variation of such rocks than anyone can reasonably be expected to possess. Further, the fact that one is comparing an outcrop existing today with a fragment broken off in some past geological period is liable to lead to faulty correlations ; there is likely to have been variation down the dip as well as along the strike, and levels available for study today are not those of yesterday. Secondly, the other great difficulty in work of this kind lies in the impossibility of being certain whether a given pebble is a first-hand contribution to the bed in which it occurred or whether it had been derived at second or third hand from some pre-existing pebble-bed. The sole evidence is the degree of rounding of the pebbles ; but here again several incalculable factors are involved. A chance angular pebble may mean nothing more significant than that a previously cracked one had gone to pieces, and tells exactly nothing of the distance it has travelled from its source. In the case of the Lower Greensand cherts, including some of all types, it is possible to collect large numbers of very bizarre shapes with sharp, though slightly rounded edges. It is difficult to believe that they have travelled any considerable distance, and leads to the belief that they were derived from a now buried outcrop on the London Platform. The evidence of the quartzites and vein-quartz pebbles in this connection will be considered in due course. The third incalculable factor is longshore drift. The evidence of the rhomb-bearing cherts, discussed above, suggests a drift from the east, but, as will be shown, the evidence is conflicting when other types of rock are considered.

(v) *The Rotted Cherts.*

One feature of the cherts remains for consideration. At first sight many of the cherts from Westwood's and Squerrye's pits look very different from those in the Lower Folkestone and Hythe beds. There is definitely a preponderance of light grey to white cherts,

and many of these have rotted in a curious manner. The white cherts in some cases at least have arisen merely by the depigmentation of the pebbles ; some of the largest still have a small, dark-coloured, unaltered core, and some of the coloured cherts exhibit concentric banding exactly comparable with that shown by the flint pebbles in Hertfordshire Puddingstone. But the rotted cherts, which make up a high proportion of the total of the Upper Folkestone pebbles, have been altered in a much more drastic fashion, akin perhaps to lateritisation.¹ The change has gone so far in some instances that nothing remains, superficially at least, to prove that the pebbles were ever cherts ; but others show the half-way stage, and traces of original structures remain. Curiously enough, the alteration seems to be more internal than external, as some still have a thin skin of hard chert, though the interior is soft and powdery. Obviously they could not have been transported in their present condition, and the rotting must have taken place *after* they were embedded in their present matrix ; they often show beach-hammering marks on the surface.

(b) The Phosphatic Pebbles.

Among the high yield of phosphatic pebbles from the Upper Hythe beds several different classes of material are represented. The easiest to identify are distinctive phosphatic, glauconitic grits. The surface of these is usually glazed, while the colour varies from deep chocolate-brown to yellow, and rarely to cream (in the occasional Upper Folkestone specimens). The distinctive feature is a peppering with sharply angular, quite unworn chips of quartz, together with larger grains of glauconite. In some other specimens glauconite fails, the quartz chips are very small and accompanied by a sprinkling of crushed fragments of bone and other indigestible material of like kinds. This is almost certainly coprolitic material evacuated by some creature which took its food from the sea-floor. Some of the phosphate acts as matrix to well-rounded quartz grains, the rock being phosphatic sandstone, and a large number contain neither quartz nor glauconite. The latter are difficult to deal with, as they so closely resemble some types of chert ; it requires considerable experience before one can confidently distinguish between some rhomb-bearing cherts and some phosphatic grits, and a test of either streak or hardness may be necessary. Often, however, the surface of an otherwise difficult phosphatic pebble shows significant grooves produced naturally. In such cases no further test is necessary, of course.

There are also locally large numbers of small fragments of bone, fish teeth and spines. One sample from Mid Street, Nutfield, yielded half-a-dozen fragments of fish teeth, but they may well be

¹ A similar rotting of flint pebbles has been described by A. L. Leach [32].

the remains of one creature, probably Cretaceous, and of no more significance than the pieces of siliceous sponges or the spicules of *Geodites* frequently recorded from the matrix of the pebble-beds by Gossling. It is otherwise, of course, with the relatively rare fragments of ammonites, preserved in phosphate. These have proved rarely identifiable, but Dr. Spath has kindly examined our material and has recorded fragments of Oxfordian ammonites, including *Quenstedtoceras mariae* from the Upper Hythe beds of Bell Street, Reigate and Redstone Hill, Redhill. The material of which these casts of ammonite chambers is made is indistinguishable from many of the phosphate pebbles showing no trace of organic structure, and one is led to believe that this also has been derived from the Jurassic strata which abut against the flank of the buried Palaeozoic massif under the London area. Similar phosphatic material has already been demonstrated in the Bargate Beds of more westerly outcrops to have been derived from the Jurassic [4].

(c) The Ironstone Pebbles.

Although ironstone is such an important component of the Upper Hythe pebble suite, there is little by way of description that can profitably be said about it. In an average sample the majority of the "pebbles" are really fragments of iron-ore occurring as flat, angular and often quite unworn chips evidently derived from the break-up of iron-pan like that occurring abundantly in the Lower Greensand, and of penecontemporaneous origin. Small ferruginous nodules, resembling kidney iron-ore on a micro-scale, is also possibly of contemporaneous, concretionary origin, but some may be genuine oolitic iron-ore. From the petrographical point of view the most interesting of the ferruginous pebbles are oolitic ironstones, which consist of ovoid to subspherical ooliths of limonite, usually with quartz chips acting as nuclei (Fig. 16) and with strongly developed concentric structure. Structurally these pebbles can be matched by any of the well-known oolitic ironstones in the Jurassic or Palaeozoic, but the original mineral was iron-silicate, not hydrated iron-oxide as in our pebbles. As the pebbles would be derived from the outer weathered portion of the ore, and on account of their small size would in any case suffer extreme alteration, this difference may be of no significance. Similar material has been described from the Carstone on the other side of the Palaeozoic Platform in Lincolnshire, but is regarded as being authigenous. We are not prepared to dogmatise on this point, but the pebbles appear to have experienced a certain amount of transportation. If our few pebbles of this type have been derived from some older formation, the Corallian is a not impossible source.



FIG. 16.—OOLITIC FERRUGINOUS GRIT. PEBBLE FROM UPPER HYTHE BEDS. Sharply angular quartz chips embedded in matrix of limonite, largely oolitic.

(d) Pebbles of Igneous and Pneumatolytic Origin.

Pebbles of igneous origin are not abundant and all those so far discovered are of acid composition and of fine grain-size. The Hythe pebble beds yielded none in this district, but from both divisions of the Folkestone beds a small number have been collected from most exposures. The largest pebbles have come from Westwood's and Squerrye's pits, where they reach an inch in diameter, though usually they are smaller than this. On the Lower Folkestone horizon the largest yield has come from the Oxted and Limpsfield pit.

Two rock-types are represented: the majority are rhyolites, the remainder are identical in mineral composition but of slightly coarser grain, so that porphyritic microgranite is a more suitable name. Both were derived, if not from one rock-body, certainly

from closely related ones. As far as one can judge from a meagre amount of material they represent lava-flows and possibly dyke-rocks. The colour-range of the pebbles is wide : the majority are pale buff, a few are light pink and one or two have a purplish tinge, while several from the Moorhouse pits are white. The specimens from the Lower Folkestone Horizon vary between yellow-ochre and rusty brown. There is little doubt, however, that originally they were all of one colour, and we hope it is more than wishful thinking when we suggest purplish as the most likely tint. The light pink ones are in the process of being bleached, while the Upper Folkestone specimens have lost all their colour in the same manner as many of the cherts from the same pits, as shown above. The yellow and brown rhyolites occur in the highly ferruginous sands, typically in the Oxted pit, and have imbibed limonitic pigment from the sand.

The distinctive feature of the typical rhyolites is the occurrence of microphenocrysts of beta-quartz up to about one millimetre in size. Occasionally these are milky white, and are scarcely visible against the light groundmass of some specimens, but usually they are dark-coloured and stand out prominently (Pl. 8). With a lens the characteristic corrosion inlets and thermal chips displaced by viscous flow may be seen. In one type the phenocrysts are narrowly rimmed with a fine graphic intergrowth, while in another the groundmass consists of small imperfect spherulites. Either a flow-breccia or an acid tuff is represented by another single pebble which differs markedly in texture in sharply defined areas ; some are cryptocrystalline and flow-banded, others felsitic and probably in the glassy condition originally. The feldspars are unfortunately thoroughly decomposed so that identification is out of the question. The lateritisation that caused the rotting of the cherts after they were incorporated in the Folkestone Sands has had even more drastic effects on these much less stable igneous rocks, so that the rhyolite has been altered into a chalky substance easily scraped away with the finger-nail, though its original toughness is proved by the fact that the quartzes have been ground smooth with the surface of the pebble.

It may be noted that the number of these pebbles has probably been under-estimated ; among these rhyolites there may well have been some without phenocrysts, and these would be indistinguishable from some of the arenaceous sedimentary types. Even some of those with phenocrysts are uncomfortably similar to some of the quartzites containing porphyroblastic quartzes set in a finer matrix.

As regards provenance, Professor P. Pruvost, after examination of our material, kindly expressed his opinion that the rhyolites are undoubtedly Armorican. They bear a very close superficial resemblance to the Jersey rhyolites, a fact confirmed by Dr. A. E. Mourant, particularly in the case of the rocks containing plenty of

quartz phenocrysts, but none of feldspar. The writer believes that these rocks are not of a sufficiently distinctive type to be narrowly localised; they could be matched with a moderate degree of accuracy in N. Wales, Armorica or Shropshire; the pebbles cannot have come from the south, but may well have been brought from the east by longshore drift, especially as there is independent evidence of derivation of some of the cherts from this direction. A new aspect of the problem arises, however, from the discovery of a single pebble—one only, but undoubtedly representative of many others not yet recognised—of a different type from those described above. It came from Westwood's pit in the Upper Folkestone Sands, and is a tough, dark bluish-grey rhyolite, mottled with white. In thin slice it is seen to be pneumatolytised, the whole of the feldspar having been replaced by tourmaline and quartz (Pl. 9). The phenocrysts of beta-quartz are quite normal, but the rock contains in addition sharply defined pseudomorphs of three kinds: certain of them consist exclusively of quartz-mosaic and were originally feldspars; others contain nothing but a close-packed aggregate of tourmaline grains, while the remainder consist of tourmaline, clinozoisite, white mica and quartz in intimate admixture. The rock is a tourmalinised rhyolite or elvan.

It is significant that the same horizon has yielded a few pebbles of tourmalinised killas, evidently derived from one area, though they differ among themselves in detail. Those which are most distinctive are well stratified, consisting of bands containing short prisms of tourmaline, with a little iron ore, embedded in a mosaic of quartz grains, alternating with a continuous felt of minutely crystalline tourmaline, containing near the edges of these bands a few grains of quartz. This is certainly a tourmalinised Palaeozoic greywacke. In another variety, figured in Pl. 9, more complete pneumatolysis has effectively destroyed the original characters of the rock, but it also appears to have been a clayey grit. It now contains two types of tourmaline: "massive" prisms up to a half-millimetre in length, showing zoned trigonal cross-sections, and irregular patches of tourmaline "felt" margined by impurities pushed outwards during the growth of imperfect radial aggregates which show partial black crosses between crossed nicols. In all these tourmaline-bearing rocks, igneous and sedimentary, the same kind of tourmaline occurs, with pleochroism formula: E—colourless, O—greyish green. All the pebbles are criss-crossed by minute quartz veins later than the tourmalinisation.

The only possible British source for these rocks is South-West England, with Cornwall more probable than Devon. The Armorican granites of the French mainland are not tourmalinised, according to Groves, so the obvious conclusion seems to be that we are dealing with the products of longshore drift from the South-West of England, i.e. in the opposite direction to that inferred from the



[Photo by A. V. Weatherhead.

RHYOLITE PEBBLES FROM THE UPPER FOLKESTONE BEDS, WESTWOOD'S PIT.

All three show obvious phenocrysts of beta-quartz (dark in the photographs) associated with scarcely visible and highly decomposed phenocrysts of alkali-feldspar, embedded in a light cream-coloured matrix. ($\times 5$)

[To face p. 216.

distribution of the rhomb-bearing cherts. There are two possibilities : either these tourmaline-bearing rocks came from a hidden source under South-East England, or they were derived from an older pebble-bed dating from a period when drift from west to east was in order. The first alternative cannot be proved, but in regard to the second, A. W. Groves has shown that the eastward drift of Dartmoor detritus commenced in Wealden times, and we suggest that our pebbles were derived from Wealden pebble-beds destroyed in Folkestone times. The implication of this conclusion is very important : if the tourmaline-bearing rhyolites and killas were derived, second-hand, from the Wealden, other types from the same source must be anticipated, and the nature and contents of these older pebble-beds must be taken into account before the matter can be pursued further. At this point we hand over the problem to our colleague, who has studied these beds over a wider area.

The Quartzites, etc.

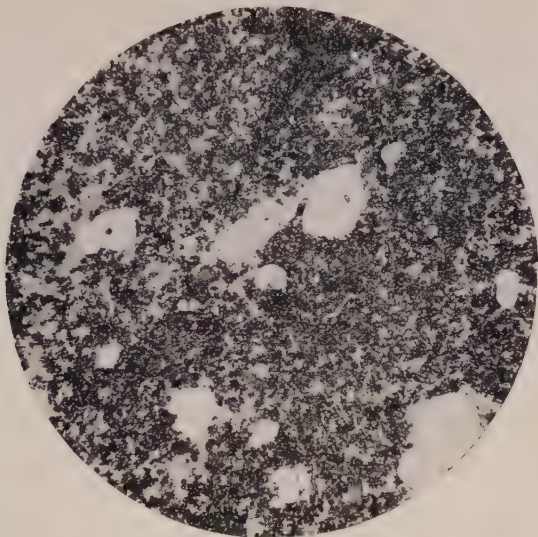
We have grouped under this omnibus heading a large variety of sedimentary and metamorphic arenaceous rock-types, the full description of which would occupy far more space than is available. They grade on the one hand into quartz-schist and on the other into arkoses and sandstones in variety. The quartzites and quartzitic sandstones vary considerably in colour ; a few are distinctly bluish, a number are buff or brown, especially from the Lower Folkestone Beds ; many are pink, while the majority of the Upper Folkestone specimens from the Moorhouse pits are off-white. Colour is no criterion of origin, however, for among the rare blue pebbles are several types which can be matched in their microscopic characters with the commoner pinks and whites. Descriptions of the salient types are given in order to establish their general character and origin.

Among the rare " blues " are some consisting of well-graded, well-rounded quartz grains, dusky with minute inclusions and cemented in the well-known fashion by secondary outgrowths in optical continuity with the original grains. A distinctive feature is the occurrence in some of the quartz grains of multitudes of minute acicular rutile needles, best seen in reflected sunlight under a high power. This is doubtless the cause of the bluish colour. A few original feldspar grains are now represented by aggregates of finely crystalline sericite. The rock is traversed by many narrow shear zones within which the quartz has been converted into a fine-grained mosaic cleared of gas bubbles and impurities. Among the pink quartzites are some which differ from the above only in minor details. They are of the millet-seed sand type, with the original grains rather more clearly outlined. The rock is traversed by closely spaced planes of inclusions suggesting resealed cleavage-planes. In addition shear-zones like those described above are

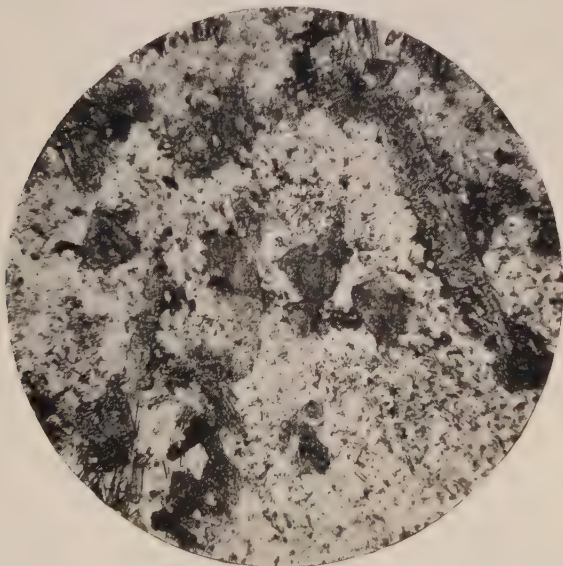
much in evidence. It will be realised that these show no significant differences from the well-known Lower Palaeozoic quartzites of which the Wrekin Quartzite is a representative type. We favour a Lower Palaeozoic age, though there is no *proof*; but the parent rock has experienced a stormy tectonic history—it shows an incipient cleavage, and at a later stage has been sheared in more than one direction.

The most distinctive of these rocks are the porphyroblastic quartzites, which contain relatively large quartz grains—phenoclasts—embedded in an opaque lighter-coloured matrix, and again traversed by shear zones and sometimes by thin quartz-veins. Sections show a complete absence of grading, of stratification or other regular orientation. The larger rounded grains have been chipped, not ground into their present shape; they are associated with angular grains with the sharpest possible angles and are set in a matrix of disorientated quartz chips of all sizes down to powder grade. The parent rock was evidently a cataclastic quartzite, a typical product of compressional metamorphism.

A metamorphic origin can obviously be claimed for another group in which parts of the rock consist of a coarse mosaic of strain-shadowed quartz grains, intricately sutured together; while parts consist either of a much finer sutured mosaic or a finely granulitic aggregate showing abrupt changes of grain-size. This has clearly experienced two metamorphic phases, the second of them cataclastic. It is tempting to claim a Precambrian age for these quartzites which owe their distinctive characters not to the conditions under which they were formed, but to their subsequent geological history. At the same time there is nothing to disprove the supposition that they are Lower Palaeozoic, originally similar to the sedimentary quartzites described above, and owe their metamorphic character to participation in the Armorican orogeny. Two points arise here. In the course of oil-exploration in East Anglia it has recently been proved that Precambrian rocks lie immediately under the Trias in Norfolk. Secondly, the typical pink quartzites and related arkosic types were submitted to Professor P. Pruvost for comment. He was impressed with their Armorican facies and suggested correlation with a named formation—the Grès d'Erquy, which outcrops on the Brittany coast between St. Malo and S. Briec, forming Cap Frehel. The exact age of these red quartzites and arkoses was then (1938) in dispute, but actually that is of secondary importance compared with the place of origin. The writer is of the opinion that these pebbles were an original, first-hand contribution to the Lower Greensand, judging from their large size, unworn condition and appearance in quantity in the highest pebble-beds examined, while being absent from the lower ones. Naturally we exclude those arenaceous rocks of other types which occur in well-rounded forms, sometimes



TOURMALINISED RHYOLITE PEBBLE FROM UPPER FOLKESTONE BEDS, LIMPSFIELD.
Ordinary light, $\times 30$.



[Photomicrogr. by A. V. Weatherhead.

TOURMALINISED 'KILLAS' PEBBLE, 6-INCH PEBBLE BAND, WESTWOOD'S PIT.
Ordinary light, $\times 120$.

[To face p. 218,

perfectly ovoid, and which have evidently either travelled a long distance from their source or, as is more likely, have been handed on from pre-existing pebble-beds, for quartzites are among the most commonly recorded constituents of pebble-beds of all ages. In this process of handing-on, they may be deposited, as derived pebbles, in a physical environment very different from that in which they originated. In the sense that some at least bear the imprint of their environment (as well as internal evidence of the conditions under which the parent rock originated) the arenaceous rocks are much more informative than cherts for example. Some of the arkoses and limonitic sandstones definitely bear the imprint of a desert origin; they show the characteristic chipping of the surface and the dull gloss described by F. Raw when dealing with the "insoliliths"—quartzite pebbles chipped by insolation—occurring in the Triassic rocks of the Midlands. Others, of crude dreikanter form, show delicate wind-etching and the typical desert glaze. On these grounds we suggest derivation ultimately from the Trias, by way of earlier pebble-beds.

There we must leave the quartzitic rocks, realising that far more are left unplaced than allocated, even tentatively, to their place in the stratigraphical column.

The Siltstones, etc.

The last group of sedimentary rocks is linked with the preceding by other varieties of intermediate character. Typically the siltstones in the Lower Folkestone Beds (which are the most distinctive) are well stratified, rather soft and carry plentiful white mica. Consequently the pebbles tend to be irregular in shape, platy in habit and subangular. Others are more firmly indurated and, with increasing grain-size, pass into the quartzites. Other pebbles of similar types occur plentifully in the Upper Folkestone beds and differ only in colour, being either pink or white. In view of what has already been said concerning the value of colour in determining species, it is uncertain whether the brown specimens are really of different origin from the pink and white ones, or whether it is merely the consequence of long burial in a richly limonitic sand-matrix. In connection with origin, the writer thought it reasonable to expect Wealden siltstones among the Lower Greensand pebbles, and was impressed by the general similarity between the two; but the senior author, with much wider knowledge of the lithology of the Wealden rocks, of which he had made a special study in another connection, believed that the Greensand siltstones were not Wealden, largely on the evidence of the higher content of material of the clay grade in the latter. Gossling therefore favoured derivation from an older rock, the Old Red Sandstone, Carboniferous or Trias being possible sources.

In thin slice some of these rocks consist of a fine-grained mosaic

of quartz grains, sutured together by secondary outgrowths, associated with white mica in large detrital flakes and in much smaller wisps, probably secondary. Some of the mica flakes and patches of chlorite presumably formed from them contain dark rutile needles. These rocks are micaceous quartzitic siltstones and fine sandstones. The stratification is emphasised by an extraordinary concentration of coloured minerals in certain bands. In these, leucoxenised ilmenite, largely converted into minute tabular anatases and bipyramidal crystals of the variety miscalled "octahedrite" are dominant; but tourmaline also is so abundant as to be practically an essential component. The crystals are euhedral, showing the usual combination of trigonal prism and obtuse trigonal pyramid; the edges and corners are quite unworn, so the mineral is definitely an original contribution from a nearby source. For most of the crystals the pleochroism formula is E—nearly colourless; O—a dark neutral tint tinged sometimes with brown, sometimes with blue. Of rather special interest are rare bicoloured prisms which demonstrate their polar symmetry by being light blue at one end and red-brown at the other. The best of these crystals is only 0.007mm. in length. Others are more or less heavily charged with opaque inclusions. Although far subordinate in amount to the tourmaline, zircon is also an important constituent occurring both as euhedral crystals and rolled grains, obviously second-hand. The euhedral forms include clear prisms capped by a bipyramid, in zone with the prism faces in some cases, but with the prism edges in others. They are characterised by large inclusions, some tubular, others in the nature of negative crystals. A few have the familiar torpedo-shape, while acicular crystals also occur. Probably the most significant are large regularly "zoned" crystals terminated by two bipyramids, and with the typical surface markings, commonly called zoning, extending right to the centre. With the intention of extending the information gained from the thin sections, some of the siltstones were crushed and the heavy minerals separated in the usual way. Care was taken to use as nearly identical pebbles in one test as possible, but the chance of mixing materials from more than one source introduces an obvious possibility of error. In these separations tourmaline covers a wider colour range than in the thin sections, "O" being dull brown, dark olive-green, dull indigo and indigo charged with black inclusions in different crystals. Occasional rolled tourmalines from another source also occur. Zoned zircons up to 0.08mm. long and clear crystals up to 0.1mm. are associated with rare ovoid grains. Other significant constituents are rutile of the normal red type, associated with unworn crystals, either yellow or dark brown in colour, and showing a combination of prisms of two orders, with very distinctive surface markings. Thin tabular fragments of light yellow colour and again with very distinctive surface markings, due apparently

to lamellar twinning, are almost identical with rutiles described by Rastall from the Jurassic of Yorkshire.¹ In a personal communication, Rastall informed us that he had not been able to trace these rutiles to their source. He considered Brittany impossible as the other minerals characteristic of that province are wanting in the Yorkshire Jurassic. In our separations, however, kyanite, like that occurring in the Lower Greensand itself, is not uncommon. One rare mineral may be significant : one separation yields chalcopyrite in golden yellow sphenoids. Milner records this mineral from coal only [36].

With regard to the interpretation of the evidence, in virtue of the abundance of tourmaline and the occurrence of zoned zircons identical in type with those occurring in the Dartmoor detritals, the West of England for the source of the minerals in some of the siltstones, though not for the siltstones themselves, is indicated. Assuming that this identification is correct, this eliminates the Devonian and Carboniferous as possible sources of the rocks, and narrows the field to the range New Red Sandstone to Wealden. Now H. H. Thomas and A. W. Grove have shown that Dartmoor detritus occurs in the N.R.S. of western England, that it is absent from the Jurassic rocks of southern England, but occurs again in the Wealden beds, even in Surrey [18]. The question arises as to whether this is genuine Dartmoor material, or possibly derived from another nearer concealed source. In this connection we would stress the unworn, perfectly euhedral nature of the minute crystals in the siltstone pebbles. This must mean one of two things : either the pebbles were brought into Surrey and Kent by longshore drift from a West of England source-rock, in which case on the evidence before us we must conclude that it was New Red Sandstone ; or the Palaeozoic Platform is cut by tourmaline-bearing rocks emanating from a still more deeply buried granite of Armorican type. The former seems much the more likely choice, for the pebbles contain Armorican zircons as well as tourmalines, which implies that the granite itself was uncovered when the siltstones were in process of formation.

This conclusion must not be taken to mean that all the pebbles in this class were derived from this one source. Some are much softer and more fragile than the quartzitic micaceous siltstones just described, and were derived from a nearer source. Reverting to the possibility of the occurrence of Wealden siltstones and sandstones, from the evidence stated above it seems to be a case of balancing the similarity of heavy-mineral content against the amount of material of the clay-grade. It is reasonable to note that our pebbles were derived from the north or north-east of the present

¹ " Rutile in the Dogger." *Geol. Mag.*, 1939, p. 112, figs. 1 and 2a opposite p. 113 adequately illustrate the characters of the grains in our siltstone pebbles.

Greensand outcrops ; the Wealden materials with which they can be compared lie to the south, and on general grounds might be expected to be of finer grain. Again it must be a case of not proven in the absence of direct evidence of the age of the pebbles, which could be established only if they were fossiliferous ; but although impressions of strongly ribbed shells have been found, only one has been generically named—*Lopha* sp. Direct comparison with samples of Palaeozoic siltstones from the bore-holes south of London conveyed the impression of general similarity, particularly with some of the Devonian material, but without further evidence we prefer to leave the matter open.

The Vein-Quartzes.

Apart from providing a convenient basis for the numerical study of the pebbles, there is little of interest attaching to the vein-quartz pebbles. Two types stand in strong contrast to one another. A proportion are large, angular, unworn stones up to about 30mm., some consisting of quartz crystals with sharp-edged prisms but with the terminations broken away. Obviously these were contributed directly to the Lower Greensand from the London Platform, and may well represent more massive veins belonging to the same suite as the thin ones which are so frequently seen cutting pebbles of different kinds—quartzites, siltstones and cherts, as noted above. There is every gradation between these and the other extreme : beautifully rounded pebbles of ovoid form which were derived from pre-existing pebble-beds. Even one horizon, the 6in. Pebble Band in the Upper Folkestone Sands has yielded a surprisingly varied collection of such derived pebbles, varying from translucent to opaque, and in colour from milky white through cream and yellow to brown, through pink to deep red and red-brown, and through grey to mauve. This colour variation is doubtless an inheritance from the environment in which the pebble was shaped and from the matrix in which it was originally embedded. There is no possibility of tracing any of them back to their ultimate origin.

Conclusion.

In work of this kind the evidence is cumulative. Much still remains to be done on the material Gossling accumulated ; scores of pebbles that could not be identified on sight have been put on one side for further study and may in time provide some of the missing links of evidence. It is a fascinating study ; and although the results achieved have fallen far short of the Authors' target, to the writer, at least, it has been worth while.

The Provenance of the Pebbles in the Lower Cretaceous Rocks

By J. F. KIRKALDY, D.Sc., F.G.S., F.R.Met.Soc.

I. INTRODUCTION

THE late Mr. Gossling devoted much time and thought to the problem of the source of the pebbles described in the preceding pages. In particular, he hoped to be able to prove in a number of cases that they had been derived from the Palaeozoic rocks of the London Platform. He combed the literature most assiduously for information as to the nature of the rocks composing the Platform and the characters and relations of the fringing Mesozoic strata. The first section of this communication is largely a précis of Mr. Gossling's notes. In the second section are given the results of the examination by the writer of the pebbles in the Lower Cretaceous beds at a number of localities, both within and outside the Weald, thus supplementing the previous communication by extending the inquiry over a wider field. In the final section the provenance of the pebbles is discussed in the light of all the previous information.

II. THE CHARACTERS OF THE ROCKS COMPOSING THE LONDON PLATFORM AND THE NATURE AND RELATIONS OF THE FRINGING MESOZOIC STRATA

The deep borings show to the north of the Kent coalfield a narrow band of Old Red Sandstone and to the west a broad belt of Lower Palaeozoic rocks extending from Chilham through Sheerness, Bobbing, Cliffe and Fobbing to Harwich and Lowestoft. To the west of this again is a wide area beneath London where only rocks of Devonian age and Old Red Sandstone facies have been proved; but to the north and north-west of London, at Ware, Little Missenden and Calvert, the Lower Palaeozoics reappear. The boreholes are somewhat few in number and often widely spaced, except in the London and east Kent areas. It cannot be safely assumed that the outcrop plan of the various formations on the upper surface of the London Platform is as simple as given above or that Pre-Cambrian rocks may not be present at some hitherto untested localities.

As regards the details of the lithology, the Lower Palaeozoic rocks are dominantly of an argillaceous facies, but subordinate harder beds of greenish-grey micaceous sandstones and thin bands of greenish-grey or grey quartzite also occur. The Devonian and Old Red Sandstone rocks are of a wide range of lithological types, such as marls, cornstones, micaceous sandstones, conglomerates

and quartzites. Certain of them will be referred to more fully later, but we note here that Prestwich described from the Kentish Town boring "a singular conglomerate, 2ft. thick, containing pebbles of a considerable size (well rounded and varying in size from a marble to a cannon ball [41, p. 14], of various old and crystalline rocks; amongst these were dark grey syenites, greenstones, red claystone-porphry, trap rock, a grey semitranslucent quartz or hornstone and a granular schist with traces of fossils" [41, p. 8]. Owing to commercial secrecy, good accounts of the Carboniferous rocks are at hand for only a few of the borings of the Kent coalfield. The Carboniferous Limestone appears to be of standard type and at Ebbsfleet both oolitic and dolomitic limestones were penetrated, together with "cherty limestones becoming darker below, but containing oolitic bands" [50, p. 71]. The main mass of the Coal Measures consisted of fireclays and shales with subordinate sandstones, mainly compact fine-grained types, but locally there were coarser varieties and also seams of conglomerate. At Bere Farm, in the lower part of the Coal Measures, two of these conglomerate bands contained pebbles of chert [42, p. 36] and at Folkestone "pebbles of quartz, black shale, chert and jasper" were also recorded from Coal Measure conglomerates [42, p. 40].

Rocks of a broadly similar lithological type are present in the eastward extension of the London Platform into northern France and Belgium, but the distribution of the outcrops is different. In the north lies a broad area of Lower Palaeozoic rocks, the Brabant Massif, fringed on the south by a complex area of Devonian and Carboniferous strata.

Throughout almost the whole of the Jurassic and the Cretaceous periods the London-Brabant Massif seems to have been a land area with its western end finally submerged during Albian times, its eastern end not until the Senonian.

The disposition of the Mesozoic beds against the Platform are summarised in Figs. 17 and 18, whilst in northern France Leroux and Pruvost have recently described the behaviour of the various Jurassic formations [33] and Marlière has traced the eastward limit of the Vraconian facies—equivalent approximately to our Upper Albian [34, Fig. 39, p. 366].

With the exception of the area to the south and east of Boulogne, Triassic rocks have been recorded only from Portsdown, Brabourne, Kingsclere and Ferrieres-en-Bray, all these borings being situated towards the centre of the Wealden-Paris basin of sedimentation. At Brabourne the basal conglomerate contained several pebbles of limestone, one showing very definite oolitic structure and others crinoid ossicles. These pebbles were all referred to the Carboniferous Limestone. The other pebbles consisted of abundant "fragments of chert, mostly small flakey more or less angular chips, sometimes almost black, but more often of a jaspery red

tint" [30, p. 53] together with red and grey quartzites, grits and sandstones. To the north-west of the Platform, Triassic beds have only been proved in borings near their outcrop.

The Lias oversteps the Trias and the Rhaetic from all sides on to the margins of the Platform (Fig. 17) and in east Kent there is also evidence of an overlapping relationship within the Lower Lias [2, p. 150]. The beds are dominantly argillaceous with, frequently in Kent, a thin basal bed resting on Coal Measures and

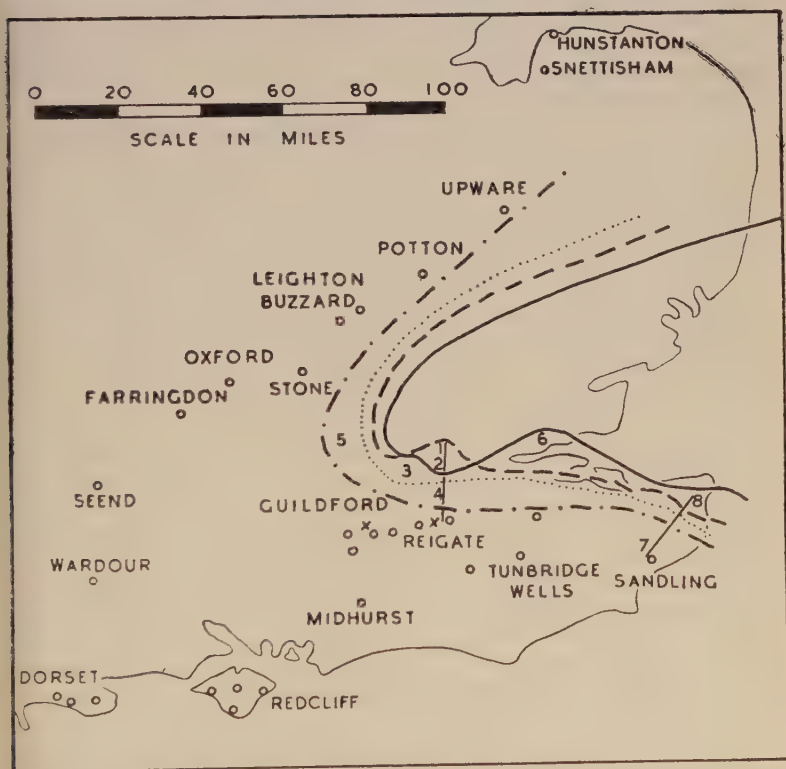


FIG. 17.—THE APPROXIMATE FEATHER-EDGE OF CERTAIN MESOZOIC ROCKS AGAINST THE LONDON PLATFORM.

Continuous thick line—Existing feather-edge of the Lower Greensand.

Dotted line " " " " Upper Jurassic.

Chain line " " " " Middle Jurassic.

Dot-dash line " " " " Lower Jurassic.

The circles mark localities in the Lower Cretaceous beds from which pebbles have been examined.

The following borings are shown: 1 Tottenham Court Road, 2 Streatham, 3 Richmond, 4 Addington, 5 Slough, 6 Fobbing, 7 Brabourne, 8 Ebbsfleet. The position of the sections shown on Fig. 18 is also indicated.

containing small pebbles of quartz and sandstone. Evidence of a shallowing of the sea is shown in several borings by the presence of pebbly-looking beds in the Middle Lias. At Chilton this seam contained pebbles of quartz up to $\frac{1}{2}$ in. in diameter [31, p. 81]. It has recently been suggested that the puzzling "granitic rock," recorded from the base of the Middle Lias of Bletchley boring in Buckinghamshire, may not be Pre-Cambrian as was first supposed, but a Middle Liassic sandstone containing granitic pebbles [61, p. 24].

The Oolites are similar in lithology to the beds of the Cotteswolds and show equally clearly in the borings of east Kent, the Bajocian Denudation and the succeeding Vesulian Transgression with the Great Oolite transgressing still further, to rest on Middle Lias at Calvert in Bucks, Southery in Norfolk and Harmansole in Kent, on Silurian at Bobbing and on Devonian at Richmond, Streatham and Tottenham Court Road in central London. The basal beds, when represented in the cores, were usually sandy and in places contained pebbles, of slate up to an inch in diameter, at Bobbing [31, pp. 157-8) and of quartz, up to the size of a marble, at Tilmanstone [2, p. 144]. At Harmansole there was a "base-ment bed of marly clay containing numerous sub-rounded pebbles of a grey sandy limestone" [2, p. 117] resting on Middle Lias and at Dover quartzose sand and fine grit occurred at the base of the sands of the Oolites, which here rest on Upper Lias [30, p. 30].

Owing to the overstep of the Lower Cretaceous beds, the Upper Jurassic strata in England do not usually extend as far towards the centre of the Platform as do the Oolites, but in France the pre-Cretaceous erosion was not so marked and in the south of the Boulonnais they overstep the Oolites [33, p. 93]. Underground in England the Upper Jurassic beds are of normal lithological character, but we may note that *Rhaxella* chert has not been recorded from the Corallian of any boring, nor have any cherty beds been found in the Portlandian. In the borings towards the centre of the Weald there was no break between the Kimmeridgian and the Portlandian, but in the more northerly borings in Kent, Brabourne and Ottinge, there is a sharp lithological break at the base of the Portlandian which obviously represents an important nonsequence, probably at the level of the Upper Lydite Bed of Oxford and Bucks [2, pp. 516-7], though no lydites have been found. In the Boulonnais, however, the Portlandian is not only very arenaceous, but contains seams of pebbles which consist of red, rose and white quartz, angular fragments of grey or black quartzite referred by Parent to the Cambrian or Silurian [40], flat pebbles of Famennian psammite and much fractured pebbles of limestone, closely resembling the local Carboniferous Limestone. Barrois, who made a special study of the cherts, records two types; one black and rolled, containing crinoidal ossicles and matchable by the cherts in the *Productus*

giganteus beds and the other white, flat and little rolled, yielding *Endothyra*, *Textularia* and other foraminifera. This fauna was regarded as Viséan, but Barrois did not know of any suitable source rocks in either France or Belgium [5]. In addition there were slightly rolled pebbles of sandstone and limestone yielding Kimmeridgian and Portlandian fossils.

Pebbles of Palaeozoic type first appear in the exposed Jurassic rocks in the Corallian between Chippenham and Wheatley (Fig. 19). Arkell regards them as having been most probably brought from the London Platform by a river which entered the sea near Marcham [2], but one pebble of micro-porphyrific soda-rhyolite, matchable amongst the Carboniferous conglomerates of the Winterbourne boring near Bristol, suggests that there may have been some derivation from the west in addition [1, p. 51]. From the Vale of Wardour to the northern boundary of Buckinghamshire (Fig. 19), pebbles of Palaeozoic aspect occur in the Lower and Upper Lydite Beds of the upper Kimmeridgian and lower Portlandian. Neaverson recorded cherts, some containing spicules of the Carboniferous sponge *Hyalostelia*, others showing oolitic structure [39], whilst Morley Davies has found a few pebbles of spherulitic felsite [38, p. 20]. Neaverson favoured a northerly origin, possibly from the Midlands, for these pebbles, but Arkell has suggested that they may not be first-hand, but have come at second or third-hand from the London Platform [2, p. 515].

The Lydite Beds reflect a major change in geographical conditions. In late Jurassic and early Cretaceous times uplift across the southern Midlands separated the southern Wealden-Paris basin of deposition from the northern basin. In the one were deposited the marine Portlandian, the lagoonal Purbeckian and the deltaic Wealden strata, in the other marine Lower Cretaceous rocks rest nonsequentially on Kimmeridge Clay or older rocks. This uplifted area can be best regarded as an extension in a westerly or north-westerly direction of the London Platform.

The Wealden Beds thin rapidly as they are traced from the centre of the basin towards the uplifted area and also overstep across the baset edges of the older strata (Fig. 18). Pruvost has shown that in the Boulonnais, thin Wealden beds rest on all horizons of the Jurassics and, around Hardinghen, on Palaeozoic beds, and also that there was an important phase, the "Boulonnais" phase of earth movements, which affected the Jurassic but not the Cretaceous rocks [43]. Dutertre has described the very varied lithology of the Wealden beds which include pebbly and gravelly seams containing pebbles of quartzite, psammite from the Famennian and limestone and chert from the Carboniferous [14, p. 242]. These observations are important, for they give the setting in which to place the rather meagre details available from the boreholes of east Kent. There the Wealden beds overstep the various horizons of the Jurassic

rocks until, around Ebbsfleet, they rest directly on Coal Measures. Lithologically the beds can usually be divided into a clayey upper portion and a more arenaceous lower division, with in places as at Maydensole [31, p. 136], Ebbsfleet [31, p. 179) and Dover [30 pp. 15-19), pebbly seams. Unfortunately at most borings only the most meagre details concerning the Wealden Beds are available, but at Dover it was noted that "the largest pebble seen was an oval pebble of dark quartzite measuring 4 inches by 2 inches; we also obtained a smaller one of liver-coloured quartzite or quartz, and another dark hard grit or quartzite; but pebbles other than those of white vein-quartz were exceptional." Further westwards Wealden Beds were missing at Bobbing, in the Chatham group of borings, and beneath central, west and south-west London. Recently they have been proved to an incompleteness of nearly 400ft. at Addington, near Croydon [8, pp. 7-9), but six miles to the north-west at Streatham they have been cut out by the transgressive marine Cretaceous rocks. Westwards and north-westwards of this there is no information as to the nature of the Wealden Beds, except that they are absent around Slough, until they appear again at the surface in the neighbourhood of Oxford and Aylesbury. There the Shotover Sands rest nonsequentially on either Purbeckian or Portlandian beds and consist of a thin but very variable succession of strongly ferruginous sands and clays with local pebbly seams.

The writer has recently described the relations of the Lower Greensand in the eastern Weald and the Boulonnais [28]. The salient points to be noted here are that within a few miles of their outcrop the Hythe Beds completely disappear, having been overstepped by the Sandgate Beds, which are succeeded by a thin development of Folkestone Beds, often difficult to distinguish in borehole records from the pebbly basal beds of the Gault. Towards the north-east of the Boulonnais, around Ferques, these marine strata overstep the Wealden to rest on Carboniferous and Devonian rocks. In east Kent the same overstep is recognisable, the Sandgate Beds resting on Oxford Clay around Chatham and on the Lower Palaeozoics at Cliffe, Sheerness and Fobbing [28, p. 113]. In the more northerly borings the beds are often coarse and gritty and though actual records of the pebbles are few we may note that at Fobbing a pebble of greenish rock (a volcanic ash) and one of coarse gritty sandstone were said to have been obtained [10, p. 133]. At the outcrop along the northern side of the Weald, pebbly seams are restricted in the east to the Folkestone Beds, but in Surrey they are also developed near the top of the Hythe Beds and around Guildford in the Bargate Beds, which are the lower part of the Sandgate Beds. Both these pebbly phases disappear as the beds are traced southwards away from the London Platform and throughout Sussex, pebbly developments are restricted to the Folkestone Beds. Underground in Surrey, as in Kent, the Hythe

Beds disappear within a few miles of their outcrop, but so also does the Atherfield Clay (Fig. 18), which in Kent persists nearly as far northwards as the Wealden Beds [28, p. 115]. At Addington [8, pp. 7-9], less than eight miles from the outcrop, there was no trace of either of the two lower divisions of the Lower Greensand, the 130ft. of beds present consisting of coarse, often gravelly, sands above underlain by more argillaceous beds of the typical Sandgate lithology. At Streatham the Lower Greensand is completely cut out by the Gault, which rests on Great Oolite, but at Richmond these two formations are separated by 10ft. of sandy

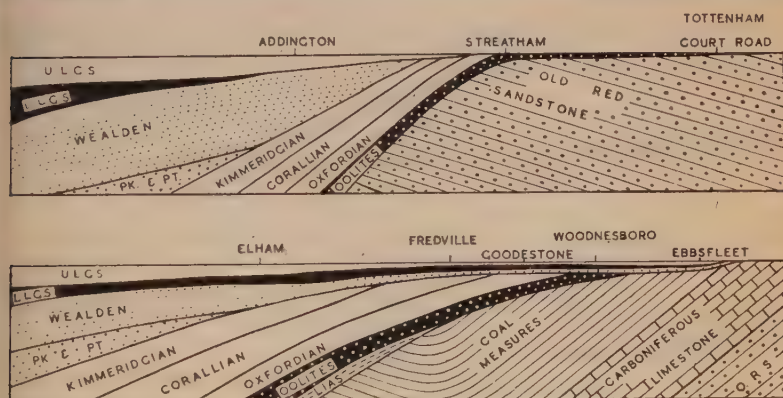


FIG. 18.—Sections (approximately to scale) to show the relations of the various members of the Mesozoic strata against the London Platform in Surrey (above) and east Kent (below).

The lines of section pass through or near the borings shown.

U.L.G.S. ... Folkestone Beds and Sandgate Beds.

L.L.G.S. ... Hythe Beds and Atherfield Clay.

Pk. & Pt. ... Purbeck and Portland Beds.

Thicknesses are in each case measured or estimated from beneath the base of the Gault, which forms the upper horizontal line.

The vertical scale is considerably exaggerated.

limestones, very similar in lithology to the Bargate Beds. The thin basal bed contained "many subangular and rounded fragments, some of them of ovoid shape, of a micaceous sandstone, strikingly like that of the Coal Measures, of quartzite and indurated sandstone, of subcrystalline limestone and other hard rocks, with some particles of anthracite" [23, p. 739] together with derived fragments and fossils from the Great Oolite.

To the west and north-west of the Platform, the borings are much more widely spaced. A group of wells around Slough and Maidenhead proved fine-grained sands of the Lower Greensand with some seams of grit and scattered pebbles, resting on Oxford

Clay [49, pp. 6-9]. When the beds reappear at the surface beyond the Chalk Downs, they consist of sands, often coarse and even gravelly, resting on Corallian and Kimmeridge Clay. The writer has recently suggested that these beds are to be correlated with the Sandgate Beds of the Weald and that they were deposited during the transgressive phase which carried the sea well beyond its limits when the Hythe Beds and the Atherfield Clay were laid down [24].

Farther north-eastwards pebble beds are well developed in the Woburn Sands of Bedfordshire and Cambridgeshire, in the Carstone of Norfolk and Lincolnshire and in the Spilsby Sandstone of Lincolnshire. They were all the deposits of the northern basin mentioned earlier and were laid down by a sea transgressing southwards to submerge, in Upper Aptian times, the isthmus which had previously joined the London Platform to the land areas of the Midlands [29, Fig. 37, p. 412]. Underground the Lower Greensand has been definitely proved on the edge of the Platform, only at Lowestoft and Culford. At the former, sandy clays with a basal pebble bed containing pebbles of quartz and occasional lydianstones and mudstones overlay the Silurian [51], whilst at the latter the succession was quartzose sands with limestones below resting on Silurian. The limestones resembled in many particulars those of Richmond (p. 229) and the Bargate Beds of west Surrey [58].

The transgressive Middle and Upper Aptian sea swept completely across the Platform and in many borings, as at Richmond [23] and Ware [58], the thin phosphatic basal bed of the Gault contained small pebbles of quartz and, more rarely, of the underlying Palaeozoic rocks. How far eastwards this transgression extended it is impossible to say, for in many borings in northern France and in Belgium the Chalk is underlain by thin pebbly beds whose precise age is still somewhat uncertain.

The preceding pages have shown that there was much oscillation of the sea margin round the Platform; each transgressive phase must have destroyed a part of the feather-edge of the underlying formations. It must, therefore, be clearly realised that the boundaries of the various Mesozoic formations shown on Fig. 17 are existing and not original limits. The presence, for example, of Great Oolite of normal lithological character in the Tottenham Court Road boring suggests that the Bathonian strata must have originally extended over much of the Platform; pre-Gault erosion has clipped back their feather-edge an unknown distance.

III. PEBBLE BEDS IN THE LOWER CRETACEOUS ROCKS OF OTHER LOCALITIES

Collections of pebbles, usually consisting of a thousand or more, have been examined from the localities shown on Fig. 17. It

cannot be claimed that the pebbles from any one locality have been studied in such minute detail as those described by Dr. Wells, but the work was carried on concurrently, the same types were sought and the differences noted.

The 'quartz grit' of the Wealden Beds of Dorset has yielded the following very distinctive pebble suite :—

	<i>Steeple.</i>	<i>Lulworth Cove.</i>	<i>Dungy Head.</i>	<i>Durdle Door.</i>
Vein Quartz	71.1	72.5	67.1	60.5
Schorlaceous Quartz	14.7	4.5	2.4	4.0
Chert	10.9	14.2	22.5	21.8
Killas	3.3	5.2	3.4	2.6
Quartzite	—	2.6	0.6	3.5
Sandstone	—	1.0	4.0	7.6

Percentages in each case are by weight.

The pebbles as a whole are markedly angular and the majority must have been derived at first hand. The killas and the schorlaceous quartz must have come from the metamorphic rocks of one of the west of England granites. The evidence of the cherts shows that this must almost certainly have been Dartmoor. The pebbles are a distinctive blue-grey colour and a few of them when sectioned were found to contain radiolaria. Dr. K. P. Oakley has been kind enough to furnish a note on certain slides (p. 255), which he found contained radiolaria characteristic of the Culm Measures. Thin sections of these cherts were compared with the extensive series of slides of Portlandian cherts in the Raisin Collection of the British Museum (Natural History) and in the collections of the Geological Survey, but no diagnostic resemblances could be found. Some of the quartzites and sandstones show features which can be matched in the New Red Sandstone rocks, but as emphasised by Dr. Wells this is not very certain evidence. The presence of much Dartmoor material in the Wealden Beds of Dorset has already been pointed out by Groves from his study of the heavy minerals [18]. The inference to be drawn from the pebble suite given above is that the Wealden Beds must have originally extended right up to the fringes of Dartmoor, probably in large part as a series of fluvatile sands and gravels comparable with those which formed the Bagshot Beds in Tertiary times. If we are right in assuming that the Portlandian cherts are not present in the Wealden Beds, the Purbeck Beds also must have extended well to the west of their present outcrops.

It is interesting to note that in a small collection of pebbles from the basal Gault of Dungy Head, kindly sent by Dr. Arkell, there was a pebble of silicified oolite. It is surely reasonable to regard this pebble as having been derived from the Portlandian, for the Gault near Osmington oversteps across the outcrop of the Portlandian, which is known elsewhere to contain oolitic cherts.

In the Isle of Wight collections have been examined from the localities listed below :—

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)
Quartz	85.0	10.8	16.2	87.7	24.1	4.7	36.3	65.5	53.6	65.1
Chert	10.7	20.1	24.8	10.0	16.6	2.8	32.5	16.8	23.6	20.8
Quartzite	4.3	1.0	—	1.5	2.0	—	6.3	3.8	2.3	2.7
Phosphate	—	50.4	—	—	19.1	73.3	21.4	—	—	1.4
Sandstone	—	17.7	4.6	0.8	3.5	—	3.5	4.1	1.9	4.3
Ironstone	—	—	74.4	—	24.7	19.2	—	10.0	18.6	5.4
Claystone	—	—	—	—	—	—	—	—	—	0.3

- (i) Pebble bed 26ft. below top of the Ferruginous Sands, Compton Bay.
(ii) " " 54ft. " " " "
(iii) " " at the top of the ferruginous development in the new road cutting above Compton Bay. About the middle of the Ferruginous Sands.
(iv) " " at the base of local Group XIII, Knock Cliff.
(v) " " 51ft. below top of the Ferruginous Sands, Redcliff
(vi) " " 48ft. " " " "
(vii) " " in the Carstone, Compton Bay. " "
(viii) " " " " Reith Bay, St. Catherines.
(ix) " " " " Rockley, near Newport.
(x) " " " " Redcliff.

Comparison of this table with that on p. 231 will show at once that the pebble suite is markedly different from that from Dorset. The complete absence of pebbles carrying tourmaline will be noted and the appearance at some horizons of phosphate in large, often very large, quantities. Secondly, the chert pebbles are of a different type. In shape they vary from well rounded to tabular with rounded corners. In colour they are much more varied than those of Dorset and range from dense black, through shades of pale grey to browns and reds. Oolitic, rhomb-bearing, brecciated and spherulitic pebbles were recognised under the binocular microscope in very small quantities (1-2 per cent of the total cherts) in nearly all samples. Unfortunately no identifiable organic remains were noted. Casts of fossils were found only in the upper phosphatic nodule bed of the Ferruginous Sands of Redcliff. They were submitted to Dr. Arkell, who regarded them as an upper Kimmeridge Clay assemblage and suggested that they may have been phosphatised before they left the Kimmeridge Clay, for he had found similar nodules in the *Pavlovia rotunda* zone of Ringstead Bay, Dorset. The fact that many of the nodules were bored externally supports this view. None of the quartzites collected showed obvious signs of a metamorphic origin, whilst the great bulk of the sandstones were soft brown fine-grained, often slightly micaceous, pebbles which could not have travelled far.

Collections have also been examined from the following localities lying to the west of the outcrop of the Chalk : The Shotover Sands of Stone, near Aylesbury, the Lower Greensand of the Vale of Wardour, Seend, Farringdon and the Oxford area as well as from

several exposures in the upper part of the Woburn Sands near Leighton Buzzard. The general character of the suite was everywhere broadly similar to that just described from the Isle of Wight but with a considerably increased proportion of chert (up to 85 per cent of the total suite at Chawley, Oxford, 74 per cent at Stone and over 55 per cent in several pits near Leighton Buzzard) and also of quartzite (18 per cent at Seend and the Red Gravel, Farringdon, and over 8 per cent in parts of the Woburn Sands). No pebbles carrying tourmaline could be found. The cherts were mainly well rounded and displayed a wide range of colouring and degree of polishing. Oolitic cherts were found in very small quantities at nearly all localities and were most abundant at Stone, where they comprised 3 per cent of the total cherts. In the south rhomb-bearing cherts were noted only at Farringdon and Stone, but they were more plentiful, though still very rare, in the Woburn Sands. Dr. K. P. Oakley has kindly determined the Carboniferous foraminifera *Archaeodiscus karreri* (Brady), ? *Saccaminopsis carteri* (Brady) and *Endothyra* sp. in a pebble from Stone, whilst of another pebble from the 21 Acre Pit, Shenley Hill, Leighton Buzzard, he writes: "Numerous dichotriaene spicules of a Tetractinellid sponge; probably *Stellata* or some allied form. The chert also contains scattered ostracod valves. There can be little doubt that the chert is Jurassic in age; and I would suggest a Portland Limestone horizon as the most likely source." It should perhaps also be mentioned that Dr. Oakley regards two pebbles from the Vale of Wardour as very doubtful radiolarian cherts. The quartzites comprised a considerable range of types, and Prof. L. J. Wills, who was good enough to examine selected specimens, reports that some were not unlike the quartzites occurring in the Cambrian of the Lickey Hills and Nuneaton, whilst others were types common in the Bunter. The sandstones were mainly soft brown, flat sided, slightly micaceous pebbles, but there were a few smaller and better rounded greyish or greenish arkosic types. Phosphatic pebbles, together with teeth and fragments of bone, as well as pebbles of shelly oolitic limestone and cementstone, derived from the Upper Jurassic rocks, were restricted to Farringdon, though in the Vale of Wardour one pebble of a pale brown limestone containing *Cypris purbeckensis* Forbes was collected.

Sixty or more years ago, when the Woburn Sands were extensively worked for coprolites, Keeping and others availed themselves of the opportunity to collect the more interesting looking pebbles of the nodule beds. Examination of the material deposited in the Sedgwick Museum has confirmed the general accuracy of Keeping's descriptions of the pebbles [25], including the angular pebble of fairly tough greenish sandstone with Caradocian fossils and the devitrified pitchstone. The cherts, in the main, were similar to those described above, both oolitic and rhomb-bearing types being

noted, whilst a few contained poorly preserved crinoid ossicles. A new feature was the appearance of a few pebbles of a reddish very porcellaneous chert labelled as ? Jurassic and containing spicules of *Cidaris* and pieces of lamellibranch shell with a well marked prismatic structure. Selected pebbles were sliced and one from Potton proved to be a very heavily tourmalinised sandstone whilst another was a *Rhaxella* chert, regarded on petrological grounds by Dr. V. Wilson as much more likely to have come from the Yorkshire Jurassics than from the Arngrove Stone of Bucks. The collections were all of selected specimens, so no ideas of relative abundance could be made. The pebbles were often much larger, up to six inches in length, than those found elsewhere in the Lower Cretaceous rocks and after Hawkes' recent remarks on the doubtful authenticity of some of the erratics said to have come from the Cambridge Greensand [34], one wonders if some of the larger and more unusual pebbles labelled as from the Lower Greensand may really be Pleistocene erratics. Mr. A. G. Brighton, however, regards this possibility as very unlikely.

Twenty years ago Versey and Carter described the pebbles in the Lower Cretaceous beds of Norfolk and Lincolnshire [56]. Examination of collections from the Carstone of Hunstanton and Snettisham in Norfolk and of slides kindly lent by Dr. Versey has shown that the suite is of the familiar character with both oolitic and rhomb-bearing cherts as well as a very few of the porcellaneous cherts noted from Upware.

In the Weald large collections of pebbles were examined from immediately beneath the Grinstead Clay at Philpotts Quarry, West Hoathly, from a lower horizon of the Tunbridge Wells Sands at Strawberry Hill, near Tunbridge Wells, from numerous exposures in the Bargate Beds and from the lower part of the Folkestone Bed at Midhurst, Sussex, Great Halfpenny Lane and other exposures near Guildford, whilst smaller collections from the Folkestone Beds at West Malling and Sandling in Kent were also studied.

The two samples from the Tunbridge Wells Sands differed very considerably :—

	<i>Philpotts Quarry. J. F. K.</i>	<i>East Grinstead- West Hoathly. H. B. M.</i>	<i>Strawberry Hill. J. F. K.</i>
Quartz	52.8	65.5	56.2
Quartzite	2.6	2.6	7.2
Chert	19.3	24.7	0.5
Phosphate	16.6	—	—
Sandstone	2.9	1.3	2.4
"Chalky" Pebbles	5.8	4.5	3.3
Claystone	—	—	0.4
Shale	—	0.8	—
Oolitic Limestone	—	0.6	—

For comparison is added a smaller collection recorded by Milner from below the Grinstead Clay of the East Grinstead-West Hoathly area [35].

The presence of the phosphatic pebbles at West Hoathly is interesting. They range from phosphatic grits to nodules of almost pure collophane and include two badly abraded body chambers of ammonites, which supports Topley's old record of ammonites from the pebble bed at Lindfield [54, p. 84]. Quite a number of the quartz pebbles show distinct signs of shearing. The cherts from West Hoathly included one silicified pitchstone and several silicified oolites, but no rhomb-bearing cherts and unfortunately none with determinable organic remains. There were two distinct types of chert, the one pale grey and rather tabular with rounded corners, the other darker, often black, and well rounded. A wide range of sandstones were present at Tunbridge Wells. The "Chalky" pebbles—decomposed cherts, sandstones, vein quartz, etc., similar to those described by Wells and Gossling (p. 211)—are not restricted to the Weald, but were found in very varying amounts and degrees of alteration in nearly all the samples examined from the Lower Cretaceous pebble beds. As they have not been recorded from the "Shell-cum-Pebble" Bed [2] and the Lydite Beds [39], we may assume that the peculiar conditions necessary to produce this particular type of rotting were a feature of Cretaceous times.

The collections from the Bargate Beds were much more uniform in character, with chert pebbles always several times as numerous as quartz. The cherts were mainly black, well rounded pebbles and included a few oolitic and rhomb-bearing types. Phosphatic pebbles were always a considerable contribution and in most collections derived ammonites and fish teeth were quickly found. No additions could be made to the recently published lists of the derived fauna of the Bargate Beds [12 and 4]. Ironstone was always present in considerable amounts (up to 34 per cent). Several types were present, including angular fragments of limonitic grit, smaller well-rounded pebbles of hard ferruginous grit and soft tabular pebbles of ferruginous sandstone. The great bulk of the sandstones were flat pebbles of a soft yellow sandstone regarded by Wells as very similar to those found in the Folkestone Beds. Quartzites were rare and did not include any of obvious metamorphic origin. In general the suite was of the same family type as that found all along the western outcrop of the Lower Greensand.

The collections from the Folkestone Beds showed the same general types, but phosphates were missing except in very minute quantity in the North-West Weald, whilst the relative proportions of chert and quartz had changed very drastically. The cherts included oolitic and rhomb-bearing types, whilst one pebble from Midhurst was identified by Dr. Oakley as containing a Heteroporoid bryozoan and as ? Jurassic and another from West Malling was crowded with spicules referred with little doubt to the freshwater sponge *Spongilla purbeckensis*, Young. Another chert pebble from Midhurst contained a poorly preserved coral, which Dr. Stanley

Smith regarded as very probably the Lower Carboniferous form, *Lithostrotion junceum* Fleming. The small collection from Sandling in east Kent was interesting as containing an unusually large amount (28 per cent) of flattened pebbles with rounded corners of a fairly tough, slightly micaceous, fine-grained, greenish or brownish sandstone.

IV. THE SOURCE OF THE PEBBLES

We are now in a position to discuss what legitimate inferences can be made as to the provenance of the pebbles. As Dr. Wells has indicated, much fascinating speculation can be made as to the story told by a single pebble; for example, that containing Carodocian fossils (p. 233). One could suggest that it indicates considerable modification in the views generally held as to the palaeogeography of Ordovician times. We have tried to avoid such wilder flights of fancy.

Material of definite Dartmoor origin is abundant in the Wealden Beds of Dorset, but elsewhere it has either not been found as yet or is present in very small quantity. The heavy minerals of the sandband in the Weald Clay near Dorking [31, p. 70] and the very infrequent pebbles of killas, tourmalinised rhyolite and the more abundant siltstones described by Wells (p. 221) indicate that some Dartmoor material did reach the Weald. On general grounds this seems far more reasonable than supposing the presence of tourmaline-bearing rocks on the Platform. If there were, surely the products of their erosion would be far more abundant and widespread. Tourmalinised pebbles are known to occur in the Trias of the Midlands [20, p. 103], so that there is an alternative source for the tourmalinised sandstone from Upware (p. 234).

Groves has identified heavy minerals of Brittany type in the Weald Clay of Sandown [31, p. 71]. No unmistakable Brittany pebbles have been found in the Lower Greensand of the Isle of Wight, but Wells has found in Surrey some rhyolites and more common porphyroblastic quartzites, which closely resemble Brittany types (p. 218), but as he has suggested the case of the rhyolites cannot be regarded as proved. The presence of rhyolites at other localities, notably in the Carstone, suggests that even if the Surrey pebbles came from Brittany, those of the northern outcrops may have come from the Midlands, though not necessarily at first hand, for Versey and Carter have found [56] that these pebbles, rare in Norfolk, were absent in Lincolnshire, further away from the Platform. The same arguments as adduced for the tourmalinised pebbles can be raised against the presence of rhyolites on the Platform.

To continue the discussion of the more striking types, oolitic cherts have been shown to be widespread, though always in small quantity. There are a variety of possible sources with the

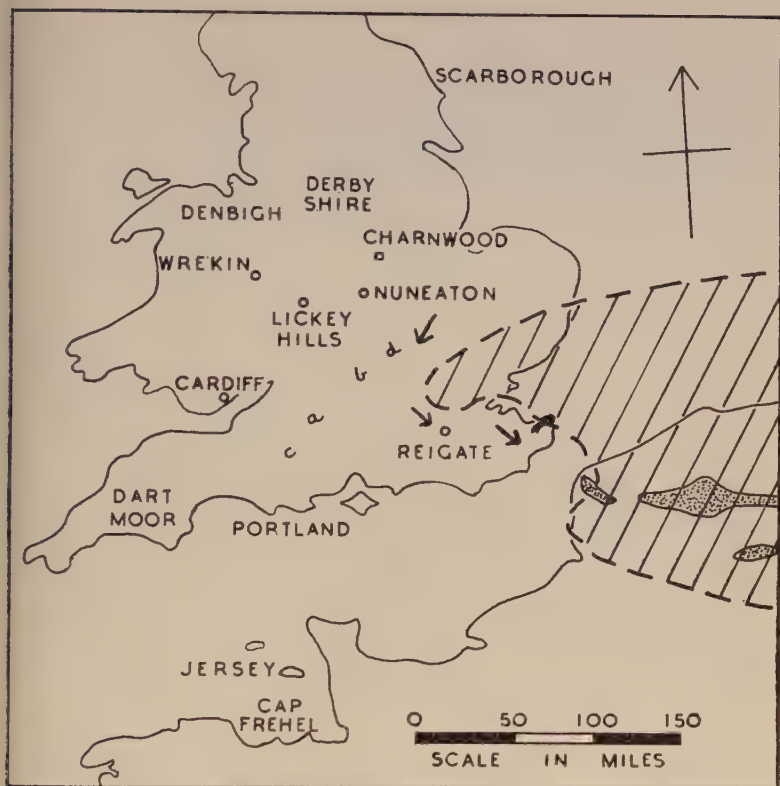


FIG. 19—MAP SHOWING THE POSSIBLE PLACES OF ORIGIN OF SOME OF THE PEBBLES MENTIONED IN THE TEXT.

The shaded area marks the probable unsubmerged portion of the London-Brabant Massif in Aptian times. Outcrops of Carboniferous Limestone on, or immediately adjacent to, this Massif are stippled.

a-b Limits of the Corallian Pebble Beds.

c-d Limits of the Lydite Beds.

The arrows show the dominant direction of current-bedding in the Lower Greensand.

Carboniferous Limestone as the most probable. The difficulty about deriving them in large part from the Portlandian as suggested above (p. 205) is that the Portland Cherty Series is, as far as we know, restricted to the area from Dorset to the Vale of Pewsey [2] and material from the west seems to have reached the Weald only in very small quantities. Against this we have the presence of oolitic cherts, nearer at hand, in the Carboniferous Limestone of the Ebbsfleet boring [50] and in Northern France [9 and 45]. It is

very unfortunate that no definite organic remains have been found associated with the ooliths.

The case of the rhomb-bearing cherts is more definite. Of the two most probable sources mentioned by Wells, the Pre-Cambrian of Brittany and the Carboniferous Limestone, the case for the latter is much stronger, both on grounds of distribution of the pebbles and in the presence of rare rhombs in cherts yielding fossils of at least a Carboniferous aspect. But whilst all the organic remains in the cherts collected by Gossling have been Carboniferous forms, we cannot regard all the cherts as Carboniferous, for at other localities both within and outside the Weald, they have been found to contain Jurassic or very probable Jurassic fossils.

Apart from Dorset, the pebble suite of the Lower Cretaceous beds is, as a whole, fairly well rounded and the proportion of really soft pebbles is everywhere low. The general impression is certainly of pebbles that have suffered considerable sorting and working over by waves, after perhaps a period of river action. Definite Jurassic material, and that usually phosphatised, is surprisingly localised. It has been found in the east of the Isle of Wight ; at Farringdon ; in the Bargate Beds and much more rarely in the top Hythe and lower Folkestone pebble beds of the north-west Weald ; a little, rather unexpectedly, at one locality in the central Weald ; and much in the coprolite seams of Cambridgeshire, though absent in many of the pebbly layers of the Woburn Sands. These are nearly all areas where the Lower Cretaceous beds either rest unconformably on the Jurassic rocks or there is good evidence to suppose that they do this in the near vicinity (for example, see 4).

Jukes-Browne was inclined to regard the pebbles as having been transported from the east and west by the rivers of Purbeck-Wealden times, the spreads of pebbly sand and shingle having been redistributed by the advancing waves of the Lower Cretaceous sea [24, p. 297]. In view of the long-continued oscillation of the sea margins against the London Platform and the presence of pebbly developments in the littoral zone of the Mesozoic rocks in a number of borings we believe that many of the pebbles must have had a far longer history than this.

The presence in early Portlandian times of great spreads of pebbles round the western end of the Platform is suggested by the existing distribution of the Lydite Beds (Fig. 19). The known facts of Portlandian geography would not preclude the incorporation of material from the Midlands, either at first hand or from now vanished earlier Mesozoic pebbly beds. Many of the pebbles must have come either first or second hand from the Platform. In this connection it should be remembered that in late Jurassic times the surface of the Platform may have been composed of different or differently distributed rocks from those which have been found in the few score of borings, whose total surface area covers an

infinitesimal fraction of the Platform. In particular, some of the chert pebbles may have been derived from outliers of Carboniferous Limestone, which either await discovery or were completely removed before the deposition of the higher Cretaceous Beds. The differences between the suites of the Folkestone Beds and the Hythe Beds (p. 201) may imply derivation of the material from slightly different directions, but may also reflect the considerable changes in the positions of the shorelines mentioned on p. 228 with fresh rock types being exposed to erosion.

The direction of current bedding in the Lower Greensand of the Weald (Fig. 19) would favour the idea of many of the pebbles having been derived from the destruction of a sheet such as that pictured above. The foresets in the western Weald slope very consistently from the north-west, though of course there are local exceptions. The beds of the eastern Weald have been less thoroughly studied, but to the best of writer's knowledge the dominant direction is the same. If this is so, there is an obvious difficulty in deriving pebbles in large quantities from the Brabant Massif, if we assume that the direction of current bedding and of long-shore drift are the same. But in the case of the Folkestone Beds, there is the possibility that the beds may be, in part, of aeolian origin and if so the direction of current bedding is of less significance. Further work is obviously necessary to determine how much weight should be paid to the evidence of the current bedding and how much to the strong resemblances between certain of the pebbles found in the Reigate area and the cherts of the Carboniferous Limestone of northern France. To the north-west of the Platform, the usual direction of current bedding is from the north-east, though again with local exceptions. This direction would favour the possibility of incorporation of material from the Midlands.

Whilst we believe that much of the material described above came originally from the London Platform, we are able to give little actual proof or, as Gossling hoped, to make many definite contributions as to the detailed nature of the rocks which make up the Platform. It is hoped that this investigation may be of value to later workers and help them in solving one of the great problems of the Lower Greensand : the source of the material of which it is composed. As Boswell has shown [6] the place of origin of its very distinctive heavy mineral suite is perhaps an even greater mystery than the original home of its pebbles.

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On the Origin of the Oolitic, Spherulitic and Rhomb-bearing Cherts

By A. KINGSLEY WELLS, D.Sc., F.G.S.

QUITE apart from the problem of their provenance, discussed in the previous paper, the cherts are of particular interest as regards their true nature and origin. Although a wholly satisfactory solution of the problem of their origin could be arrived at only after an examination of the field relations of the parent rocks, as the latter have not been located, this evidence is not available. Nevertheless, some critical evidence has been obtained from the study of their micro-characters.

1. THE OOLITIC CHERTS

So far as all three types named in the title are concerned, the problem is much the same : to decide whether the cherts resulted from silicification of calcareous sediments, or from crystallisation of silica deposited directly on the sea-floor. It may be stated at the outset that the writer concludes that the specimens which may rightly be termed oolitic cherts are almost certainly pseudomorphous after calcareous material ; that the replacement was effected by colloidal silica ; and that among the specimens originally selected as oolitic cherts are some which exhibit a true spherulitic structure.

The formation of oolitic limestone has been directly studied in the shallow seas bordering the Bahamas [19, p. 177] ; the process is well understood, and the explanation of the processes involved is widely accepted. These rocks are formed by the induration of an oolitic " sand "—an aggregate of more or less spherical ooliths that grew by accretion of crystalline carbonate about small nuclei in warm, shallow water. Gentle rolling under wave- or current-action seems to be essential in the development of oolitic structure. Induration of the oolitic sand follows infiltration of calcareous sludge into the interstices between the ooliths, and in time this crystallises to form a calcite mosaic. In a mass of colloidal material in the process of setting and crystallising, the environment is fundamentally different : oolitic accretion is impossible ; but spherulitic and ellipsoidal structures may be developed and indeed have been observed under experimental conditions. The true oolite is a self-supporting aggregate of solid bodies—the ooliths—which can touch at points only ; but with concretionary growth, as with spherulitic crystallisation, mutual interference between the growing spherules is bound to be common. In a plane section, therefore, adjacent spherules will commonly make contact along a line, instead of at a point. This provides a ready means of distinction between oolitic and spherulitic structures. Actually the criterion is most convincingly applied to a pebble mount, in which the structure is seen

stereoscopically in three dimensions ; but the examination of a thin section usually leaves no room for doubt.

With many of our pebbles there is no need to labour the point : the structural similarity to oolitic limestones is so close—indeed some are superficially indistinguishable from the latter (Pl. 7, the top pebble is a good case in point). On the other hand, some are so strikingly different that it is difficult to believe that they are fundamentally the same. The tiny pebble illustrated in Pl. 7c has scarcely a point in common with the large pebble ; but although mineralogically it might pass as an agate of the “ target ” type, the almost perfect spheres touch at points only : it therefore possesses a genuine oolitic structure which it presumably inherited, unless there is some as yet undiscovered way in which ooliths, as distinct from spherulites, of silica, can accumulate.

Normally, all the ooliths in any one specimen are alike : they consist of cryptocrystalline silica, sometimes radially disposed chalcedonite, but in many cases an exceedingly fine-grained quartz-mosaic. The radial structure is emphasised in some specimens by pigmentation by limonite (Pl. 10) ; but there is often no trace of radial structure, though strong concentric zoning may be strikingly displayed (Pls. 10, 11). As certain zones are pigmented with yellow limonite, this zoning tends to be unduly accentuated in the photomicrographs : the cores of the ooliths in Pl. 10, lower fig., are actually yellow, while the shadowy effect in Pl. 11, upper fig., is due to a blotchy yellow pigmentation that is all but invisible in the section.

In many of the rocks there is little difference between the material of the ooliths and of the matrix in which they are embedded, except in the degree of crystallisation of the silica. The matrix is invariably more coarsely crystalline than the ooliths themselves, and is usually the same kind of silica as the latter : both consist either of chalcedonite or of quartz-mosaic. The latter case is illustrated by two pebbles (Pl. 12). In the one the ooliths are well graded with an average diameter of 0.15 mm., which happens to be the diameter of the spicule of *Rhaxella*.¹ The matrix is clear granular quartz. In the second case a single oolith, more highly magnified, is shown. It consists of an almost cryptocrystalline quartz mosaic, and is all but isotropic at the centre. There is no trace of either radial or concentric structure, but it is surrounded by radially disposed blade-like crystals of quartz which are keyed into the “ wall ” of the oolith. Similarly, the zone of bladed quartz is surrounded by larger more irregular grains of roughly the same orientation. It seems reasonable to infer that the crystallisation of the silica within the oolith

¹ It is difficult to decide whether this is a genuine *Rhaxella*-chert or a normal silicified oolite. The only positive evidence favouring the first view is the size ; but this may be merely a coincidence. On the other hand there is no difference in microstructure between this and many other genuine silicified oolites, while it is completely dissimilar from Arngrove stone, and does not match exactly any of the several types of *Rhaxella* chert described by V. Wilson from the Yorkshire Corallian [60]. It is a case of “ not proven,” but with the balance of evidence in favour of an inorganic origin.

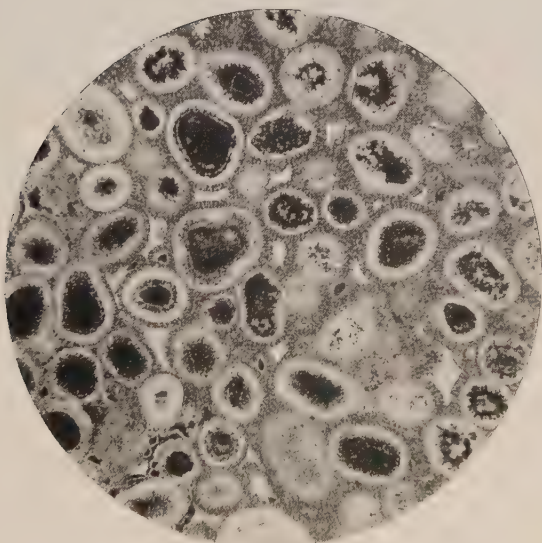
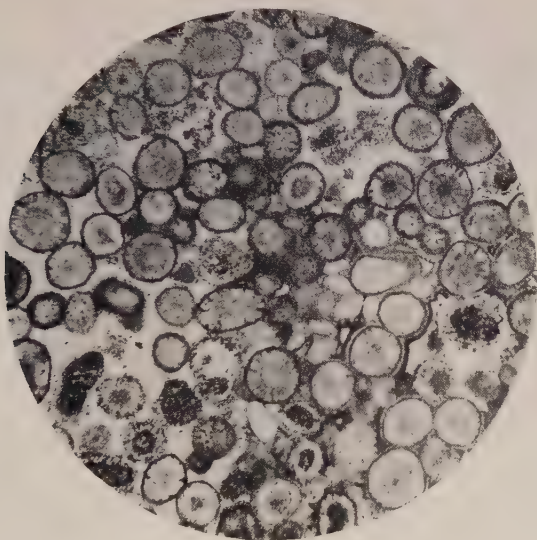
preceded that of the matrix ; but that there was no significant break in the process.

It can be demonstrated again and again that these oolitic cherts exhibit agate structure, both within the oololiths and in the matrix. The rock illustrated in Pl. 10, top fig., is a typical close-packed aggregate, with a very convincing oolitic structure : the near-spheres touch at points only, on the clearly defined outer skin of the oololiths, as shown clearly at 9 o'clock and between 11 and 12 o'clock.¹ Agate structure is apparent in the matrix between 3 and 4 o'clock, near the small light-coloured oololiths. It is much more generally developed in the pebble illustrated in Pl. 10, lower fig. The oololiths consist of a yellowish core surrounded by a light outer zone, on the outside of which the oololiths make contact. This is the original wall of the oololiths, therefore, and the medium toned zone, of very uniform width, beyond this, is not part of the oololiths, but was the first portion of the interoolith silica to crystallise out, as lightly pigmented chalcedonite. The remainder of the matrix material is clear quartz, often bladed, with the same disposition as the chalcedonite fibres. They obviously grew from the chalcedonite into the spaces, and, sometimes in association with limonite, completely fill them. Agate structure, quite independent of the nearby oololiths, is locally developed at one or two points in the figure, and involves chalcedonite, quartz and ferric hydroxide.

This very close relationship between the crystallisation of the silica in the oololiths and in the matrix, and more particularly the development of colloidal characters in both, seems to prove that the replacement of the original material was effected by colloidal silica : otherwise the colloidal characters would be meaningless. Two points arise from this conclusion. Although in some specimens the oololiths are nearly spherical, in others they convey a strong impression of having been distorted and pressed into contact (Pl. 10, lower fig.). This might well arise, of course, if the material had been a colloidal gel. Secondly, one wonders if, at the time of silicification there was any matrix. Access to the oololiths would be easy if the spaces were open ; but in any case, the relatively coarse grain of the silica in the matrix suggests that it was more easily replaced than the material of the oololiths. As diagenetic changes of this type attack the least crystallised portions first, this may indicate that the silicification preceded induration.

An extraordinary contrast in the characters of adjacent or nearby oololiths is too obvious in some rocks to be overlooked. That shown in Pl. 11, upper fig., is a case in point. Certain of the oololiths are clearly defined, they appear smooth, and are composed of crypto-crystalline pigmented " chalcedony " ; while others nearby are poorly outlined and appear speckled. These are composed of a relatively

¹ To fix the position of points of special interest in the sections we adopt the familiar expedient of imagining a clock-face superimposed on the photomicrograph.



[Photomicrogr. by A. V. Weatherhead.

THIN SECTIONS OF OOLITIC CHERT.

Above ... $\times 20$ Ordinary light.
Below ... $\times 30$.

[To face p. 244.

coarse quartz mosaic charged with minute inclusions. Between crossed nicols such oololiths tend to disappear because there is no difference, apart from the concentration of the inclusions into concentric zones, between the mosaic of the oololiths and of the matrix: indeed many of the quartz grains pay no heed whatever to the boundaries of the former. This might be due to slight original differences between the oololiths, and supports the view that the rock is an aggregate of oololiths drawn from different sources. But in any case it is a secondary change, for occasionally an oololith may be seen to consist partly of chalcedony, pigmented; but without visible inclusions, and partly of coarse quartz mosaic, as it were breaking in from outside and charged with the inclusions. As both materials are forms of silica, it is evidently a deferred recrystallisation effect.

A variant of this intimate association of pigmented chalcedony with quartz carrying inclusions is shown in Pl. 11, lower fig., the most interesting feature of which is the contrast between the core (which is quartz-mosaic), and the outer shell, which is finely cryptocrystalline. The outer shell displays a minute rhythmic banding identical with that shown by thin sections of some agates, and is a colloidal character. The boundary between the two parts is often accentuated by a heavy concentration of minute inclusions, the arrangement of which suggests that they have been pushed outwards as the change from chalcedony to quartz proceeded from the centre towards the outside.

At this point the nature of the inclusions in the quartz-mosaic becomes important. They are of three kinds. The most obvious are small granules of limonite, not invariably present, but presumably derived from the pigment of the chalcedony. Secondly, small fluid cavities, often carrying a mobile gas bubble, are abundant. Thirdly, and perhaps most significant, minute lozenges or irregular grains of carbonate can be identified. The fluid in the cavities is probably water released in the conversion of opaline silica in the "chalcedony" into quartz. There is little doubt that the grains of carbonate are residual, especially as they figure prominently in the siliceous pseudomorphs after rhombohedral carbonate crystals occurring in the cherts described in the third section of this paper (p. 250). Considered alone, the occurrence of residual carbonate in these oololiths would perhaps not be accepted as positive proof that they were once wholly calcareous; but it certainly strengthens the claim, which otherwise rests largely on the evidence of structural analogies.

The writer has been considerably influenced in his conclusions by a suite of slides of Yorkshire Corallian rocks, kindly placed at his disposal by Dr. Vernon Wilson. Some of the Corallian limestones are crowded with calcareous oololiths, at the centre of which there is sometimes a shell fragment, sometimes a calcite-filled

Rhaxella spicule. The surrounding envelope of oolitic material is almost cryptocrystalline and varies in diameter from four or five times the width of the spicule down to a mere skin. The matrix is the usual clear mosaic of calcite. Similarly some of the Corallian cherts are oolitic, the ooliths being identical in nature with those in the limestones, except that they consist of cryptocrystalline silica. Again they contain *Rhaxella* spicules; and while in some cases the infilling is now silica, in others it is still calcite—resistant presumably on account of its original coarse grain as compared with the oolith. Some of these siliceous ooliths are spangled with small granules of residual calcite, and, most significant of all, some show stages of arrested silicification. Usually certain zones have proved resistant to the change; but rarely an oolith may be divided into irregular portions, one siliceous, the other calcitic.

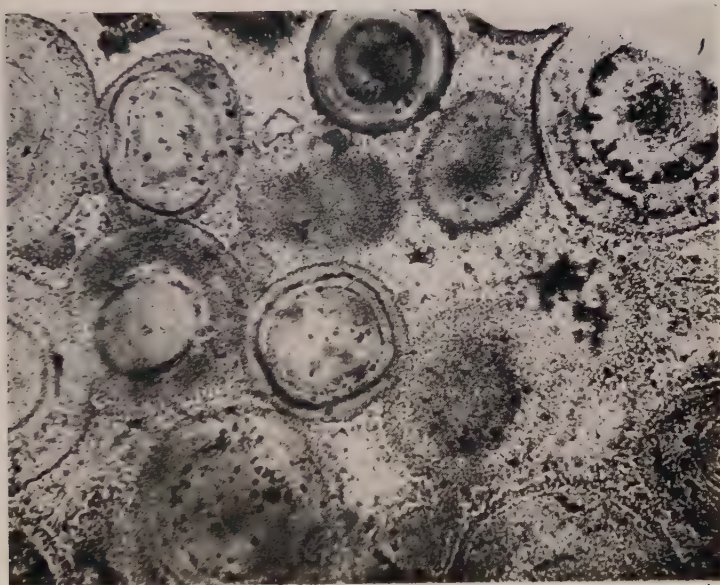
In view of this evidence it is concluded that:—

1. The pebbles of oolitic chert represent aggregates of ooliths that are believed to have been originally calcareous;
2. That the ooliths were ultimately embedded in and replaced by colloidal silica which in the process of crystallisation developed distinctive colloidal characters;
3. The original cryptocrystalline silica has in some cases been itself replaced by quartz mosaic.

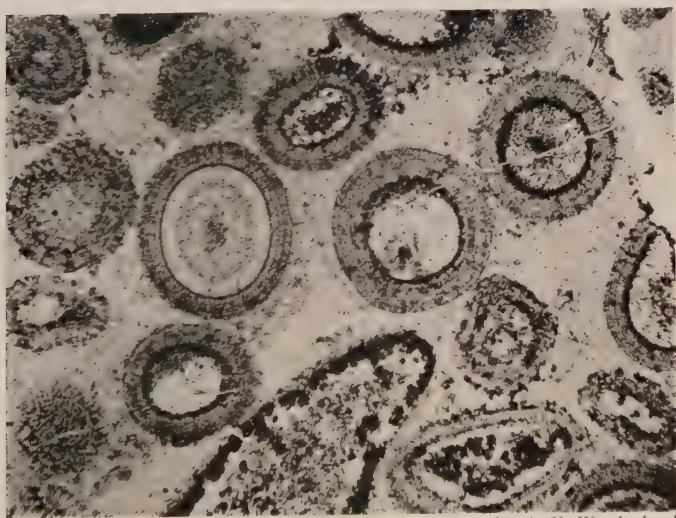
II. THE SPHERULITIC CHERTS

During the examination of the presumably oolitic cherts, some pebbles were discovered to exhibit structures inconsistent with the mode of origin usually ascribed to such rocks. In pebble-mounts of genuine oolitic cherts the structure is often beautifully displayed: the orbs are seen suspended in a more or less transparent matrix, and touch one another at points only. In these other pebbles, however, the matrix contains orbs which, though they may be isolated, are commonly grouped together into small aggregates or strung together into chains. In such aggregates and chains many of the orbs are imperfect by reason of mutual interference during crystallisation, in exactly the same manner as spherulites in glassy volcanic rocks. These are fundamentally different from the oolitic cherts in their structure, and are grouped together as spherulitic cherts.

The pebble illustrated in Fig. 20 is a beautiful example of its kind, particularly when viewed as a pebble mount; when the orbs, obviously not ooliths, appear as translucent opalescent spheres, each with a tiny limonitic nucleus at its centre. Only a proportion of these nuclei are seen in the thin section, of course, but in some instances they appear to be minute rhombs like some of those described in the next section. Many of the orbs are heavily stained with limonite, though the matrix is pure quartz, and this emphasises



[Photomicrogr. by E. O. Rowland.
Ordinary light, $\times 40$.



[Photomicrogr. by A. V. Weatherhead.
Ordinary light, $\times 30$.

THIN SECTIONS OF OOLITIC CHERT PEBBLES FROM UPPER FOLKESTONE BEDS.

[To face p. 246.

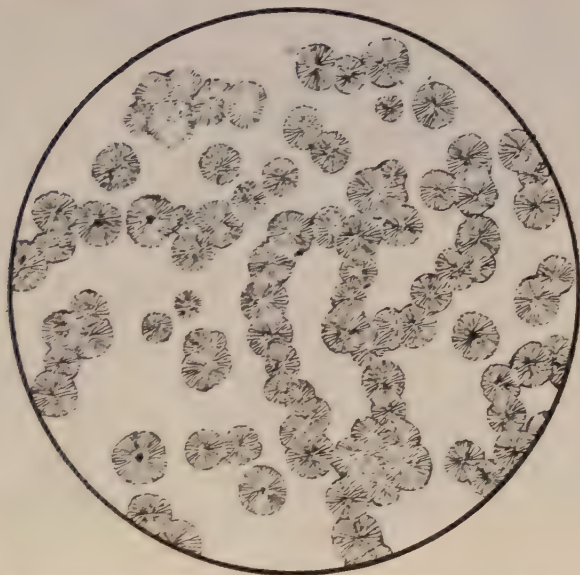


FIG. 20.—SPHERULITIC CHERT PEBBLE FROM LOWER FOLKESTONE BEDS, OXTED.
Average diameter of spherules, 0.13mm.

the radial acicular nature of the silica of which they are built. Not infrequently this radial structure within the spherules persists outwards into the matrix, when the whole rock consists of irregularly interlocking spherulites. This alignment of the blades of quartz in the matrix with the fibres of chalcedonite in the spherules recalls the similar textural arrangement noted in some of the oolitic cherts. (See Pl. 12, lower figure.)

The other spherulitic cherts illustrated show a very close association of silica with iron-ore. They are usually parti-coloured in red, brown or black associated with white or colourless patches of pure silica. The typical example illustrated in Fig. 21 shows patches of three kinds :

(1) Predominantly ferruginous containing small, usually isolated spheres of chalcedony set in a matrix of chalcedony associated with much haematite. (Fig. 21A). In the band illustrated the spheres range down from a maximum diameter of 0.15mm. at the top to 0.05 at the bottom. They are rimmed with tiny radially disposed blades of silica pigmented with red, as if the colour from the matrix had "run" a little. (2) Some parts are dominantly siliceous owing to a closer packing of the orbs, with a tendency for them to coalesce into small groups. With the reduction of the

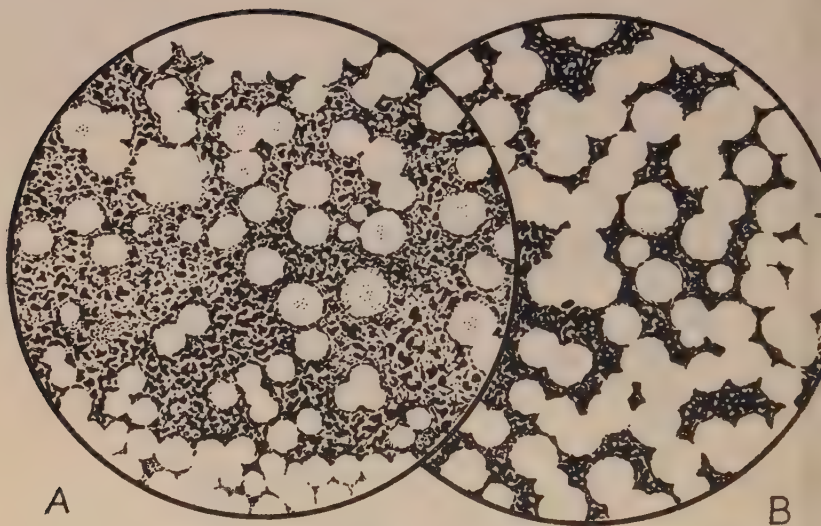


FIG. 21.—SPHERULITIC JASPER-CHERT PEBBLE FROM UPPER FOLKESTONE BEDS, WESTWOOD'S PIT.

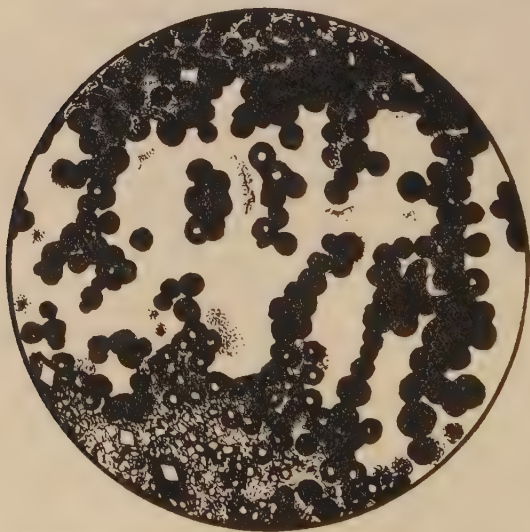
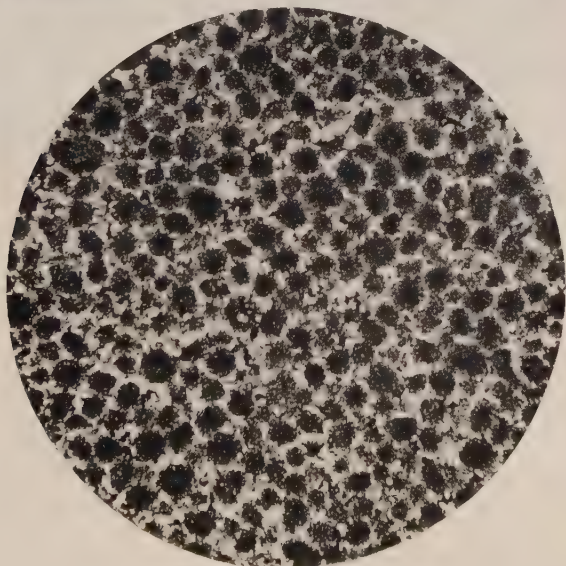


FIG. 22.—SPHERULITIC LIMONITIC CHERT PEBBLE FROM UPPER HYTHE BEDS. Coalescent globules of limonite in chalcedonic matrix. Note minute rhombs in the iron-rich portion.



[Photomicrogr. by A. V. Weatherhead.]

THIN SECTIONS OF OOLITIC CHERT PEBBLES FROM UPPER FOLKESTONE BEDS.

Crossed Nicols Top figure, $\times 130$
Bottom, $\times 30$

[To face p. 248.]

amount of matrix the haematite becomes more concentrated (Fig. 21B). Thirdly, in some areas the siliceous spheres may be so closely packed as practically to exclude the matrix except for occasional minute, but significantly shaped patches. Just beyond the boundaries of the illustration even these disappear : the rock is just a featureless white chert, giving no hint of its essentially spherulitic structure.

The pebble illustrated in Fig. 25 is representative of a variant of this silica-iron-ore association. Fundamentally it is a parti-coloured, richly limonitic chert showing patches of megascopic agate-structure. The limonitic parts of the rock are charged with spheres of pure chalcedonite, much smaller than those in the types described above, being only some 0.035mm. in maximum diameter : in places they are much smaller and much more closely packed. Even more minute spheres occur in other limonitic cherts and appear to be of opal. This is so, for instance, in the brown and white parti-coloured pebble illustrated in Fig. 22. It is the nature of the contact between the different portions which is significant. It is very sharp, but involved : the general boundary of the limonite against the pure chalcedony (shown white in the drawing) is composed of segments of limonitic spheres ; while in the chalcedony the iron-ore occurs as spheres, sometimes isolated, but usually coagulated into groups and chains. This is obviously the same structural relationship as that illustrated in Fig. 21, but with the roles of the constituent minerals reversed : the one is the antithesis of the other. It is significant that both relationships can be studied in this one small 3mm. pebble.

It is clear that in the formation of these spherulitic cherts two colloidal materials, one siliceous and the other ferruginous, were involved. Whether or not the original colloid was homogeneous is doubtful ; but the nature of the surfaces of separation between the two components, and the structural details described above indicate that they were partially immiscible : pure silica on the one hand and pure iron-ore on the other tended to separate out. This inference is supported by the results of experiments carried out by Moore and Maynard [37] on colloidal silica and ferric hydroxide in sea-water containing organic material. After a period of some months the two were more or less completely separated, with the ferric hydroxide at the bottom of the vessel, separated from the silica by a clearly defined, though highly irregular surface. The silica had developed spherulitic and "ellipsoidal" structures. There can be little doubt that the chert pebbles described above originated from similar material ; but that in the fullness of time the separation of the components was followed by setting of the gel and crystallisation. Two further points may be noted : firstly, agate-structure, with all that it implies, is commonly exhibited by the spherulitic cherts ; and secondly, small rhombs probably of siderite or ankerite,

are present in most cases. These are considered in the following section.

III. THE RHOMB-BEARING CHERTS

The general characters of these pebbles have been described in the preceding paper (p. 208). In thin section they present many points of interest, and shed some light on the problem of their origin. The tiny glistening rhombs seen in some of the pebbles prove to be siliceous pseudomorphs. Rarely they consist of quartz, each rhomb polarising as a single crystal, but much more frequently it is quartz-mosaic, charged with minute inclusions,



FIG. 23.

A.—RHOMB-BEARING CHERT PEBBLE FROM THE UPPER FOLKESTONE BEDS (BOTTOM RED SAND) OF WESTWOOD'S PIT.

Small colourless rhombs of pure fibro-chalcedony together with a few of limonite set in a cryptocrystalline limonitic silica matrix. Maximum diameter of rhombs 0.09mm.

B.—RHOMB-BEARING CHERT PEBBLE FROM THE LOWER FOLKESTONE BEDS, GREAT HALFPENNY LANE, CHILWORTH, NR. GUILDFORD, SURREY.

Rhombs, up to 0.15mm. in maximum diameter, of quartz, bearing minute bubbles and carbonate inclusions, set in a matrix of limonite-pigmented chert.

sometimes arranged zonally, in other instances distributed parallel to the original rhombohedral cleavage planes (Figs. 23, 25). The inclusions are only a few microns in size, but they include fluid cavities of most bizarre forms and granules of rhombohedral

carbonate presumed to be calcite. Within some rhombs the calcite granules are in optical parallelism, and there is no doubt that they are residual. The significance of these inclusions lies in the fact that they are identical with those already noted in the siliceous oololiths believed to have been formed from original carbonate by silicification (p. 242). In yet other specimens the rhombs consist of fibro-chalcedony (chalcedonite), the fibres of which have a negative elongation. Once more, as in the oolitic cherts, the chalcedony-infilling is apparently free from inclusions; and just as some of the siliceous oololiths were made partly of quartz-mosaic and partly of chalcedony, so are some of the rhombs.

The ferruginous rhombs which characterise other cherts are extremely variable in detail, even within the limits of one pebble. In thin section they may be lemon yellow, some deepening to orange, while others near by may be opaque limonite-brown. The lemon yellow and light brown individuals are demonstrably iron-pigmented fibro-chalcedony, differing from the chert-matrix only by being rather finer in grain than the latter. In some cases the infilling is granular quartz-mosaic together with massive (as distinct from pigmentary) limonite, which suggests that these two minerals were differentiated from the chalcedony pigmented with ferric hydroxide.

In a striking oolitic jasper pebble from the Upper Folkestone Beds, Brasted, the cores of the oololiths are very heavily pigmented and occasionally contain numbers of small, very perfect rhombs which are opaque. In view of the highly ferruginous nature of many of the cherts, both limonitic and haematitic, it is most probable that the rhombs they contain are pseudomorphs after siderite or ankerite. It must be noted, however, that pseudomorphs in pure chalcedony, probably after calcite, imbibe ferric hydroxide from the iron-rich sand (Lower Folkestone) in which the pebbles were embedded; and those on the outsides of the pebbles may become as opaque and limonitic as those referred to above. In those cases where rhombs of two different sizes, and now of different composition occur, there can be no doubt that some (the small ones) were calcite, the larger ones siderite, or other iron-rich carbonate.

A rare type provides a variant of this silica-iron association and is represented by a parti-coloured chert pebble, largely black, but irregularly mottled and streaked with light grey. In the latter portions the rhombs are only just visible by reason of a light peppering with small black specks of iron-ore. The matrix of the black parts of the pebble are similarly crowded with opaque grains, while the rhombs, with quite extraordinarily sharp edges and corners, are outlined with a skin of pyrite in the form of minute crystals or granules evicted during the crystallisation of the quartz. A wide range in the proportions of quartz to pyrite is shown (Fig. 24).

A few rhombs of a green mineral, probably a form of iron silicate, also occur.

Without entering into further details it may be stated that, in different instances, these pseudomorphs after rhombohedral carbonate consist of quartz, quartz-mosaic, chalcedonite, chalcedonite and quartz, iron-pigmented chalcedony, limonite, haematite, pyrite, pyrite and quartz, and probably iron-silicate.

So far as origin is concerned, the problem is again whether the rhomb-bearing cherts are pseudomorphs after rhomb-bearing

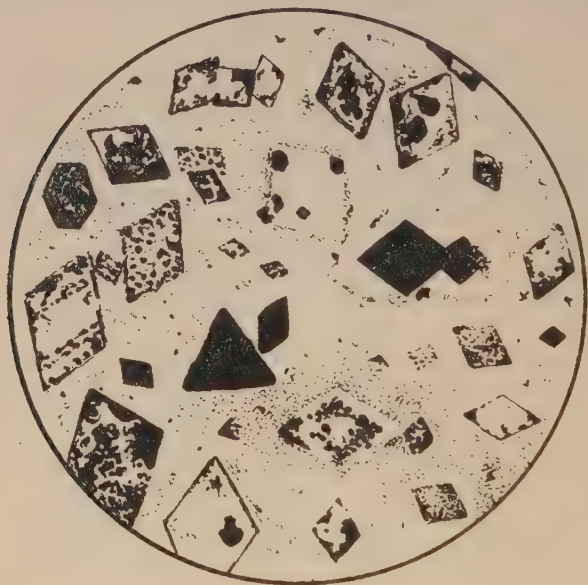


FIG. 24.—RHOMB-BEARING CHERT PEBBLE FROM THE LOWER FOLKESTONE BEDS OF GREAT HALFPENNY LANE, CHILWORTH, NR. GUILDFORD.

Rhombs of quartz-mosaic charged with varying amounts of pyrite and containing gas-filled voids. The largest rhombs have maximum diameter of 0.15mm.

limestones ; or whether the crystals were formed from a mass of gelatinous silica carrying carbonate in solution. Field evidence has been described in support of both hypotheses. On the one hand, Hatch, Rastall and Black [19] refer to chert nodules carrying rhombs of dolomite embedded in the Durness Limestone containing similar rhombs ; but Sargent and Cayeux [46, 9] for very different occurrences describe rhomb-bearing chert-nodules embedded in limestone *free from rhombs*. Jessop [22] also favoured the direct deposition hypothesis in the case of the Derbyshire cherts which he

described. Thus if the field evidence is accepted—and there is no reason to doubt the accuracy of these observations—evidently these rocks originate in two different ways.

Now with regard to the nature of the carbonate, in Carboniferous cherts from S. Wales, H. H. Thomas [53] identified it as largely dolomite, associated with fewer rhombs of siderite or ferri-ferous dolomite; and as the matrix still contains much residual calcite as well as calcitic organic fragments, this impure chert was evidently limestone, silicified after it had been partly dolomitised. As the dolomite rhombs have persisted as such in the Durness and Welsh cherts, evidently this mineral is resistant to silicification as compared with the calcite of the matrix. As the rhombs in the Lower Greensand pebbles are siliceous pseudomorphs, it is highly probable, therefore, that they were calcite, especially as Cayeux proved, by microchemical tests, that the mineral in the rocks examined by him was calcite, and that it was occasionally “quartzified.” In fact, Cayeux suggested the probable complete silicification of the calcite rhombs in rocks not then known, thus anticipating the discovery that in our pebbles this complete pseudomorphism has been attained.

Now given that the rhombs were originally calcite, one may well ask what was the nature of the medium from which they crystallised. It cannot have been limestone or even calcareous ooze, for unit rhombs have no *raison d'être* in such a medium. When the finely divided calcareous material of a potential or actual limestone undergoes crystallisation either spontaneously or under the impetus of metamorphism, it forms a mosaic of interlocking grains, not rhombohedra. However, very rarely limestones carrying rhombs of calcite do occur: a French phosphatic limestone of Eocene age and a French nodular Upper Chalk being noted by Cayeux.¹ The possibility does not arise, however, in the case of the cherts described by Sargent and Cayeux, for the nodules are embedded in limestone free from rhombs of all kinds. On this evidence these writers as well as Jessop and Renard [45] were convinced that the rhombs crystallised out of a mass of colloidal silica deposited contemporaneously with the surrounding limestone. Renard, in fact, believed that the colloidal silica had replaced limestone, and that the calcite crystals were a residuum of carbonate in the gel.

Thus the rhombs have been regarded as: (1) dolomite in a matrix of silicified limestone; (2) unspecified rhombohedral carbonate crystals deposited from colloidal silica formed contemporaneously with the limestone containing the chert-nodules; and (3) recrystallised residual calcite in colloidal silica that had replaced limestone. In our pebbles all the rhombs are silicified and there is no evidence that the chert matrix has ever been limestone: on the

¹ “Introduction à l'étude des roches sédimentaires.” Paris, 1916, Figs. 4 and 5, on Plate VII.

contrary, there is clear evidence that it was formed from colloidal silica. Agate structure is commonly exhibited, while some of the pebbles are genuinely spherulitic. A typical example is illustrated in Fig. 25. Parts of this pebble contain rhombs of light-violet pigmented chalcedonite, with the original cleavages accentuated by grains of residual carbonate. In places the rhombs are crowded together, and the original amount of carbonate must have been high. Elsewhere they are isolated in a matrix of heavily

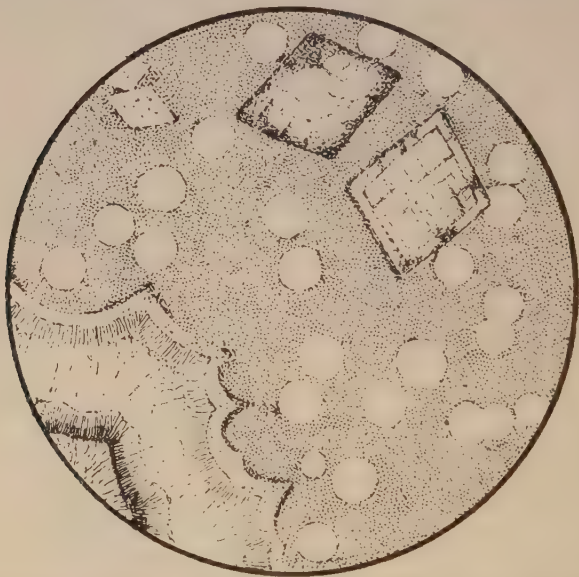


FIG. 25.—SPHERULITIC RHOMB-BEARING AGATE-CHERT PEBBLE FROM UPPER FOLKESTONE BEDS, BRASTED.

The rhombs (max. diam. 0.19mm.) are pseudomorphs of almost cryptocrystalline quartz with residual carbonate inclusions. The matrix of fibro-chalcedony is pigmented with limonite and contains orbs (0.035mm. diam.) of pure silica

pigmented limonitic chert which locally becomes involved, with clear quartz, in the agate patches. It also abounds in the small orbs of pure silica that, as noted above, are regarded as an original colloidal character. The rhombs themselves have been silicified and it therefore remains a possibility that the matrix in which they were originally embedded has also been silicified; but, if so, the replacement must have been by colloidal silica; and it cuts out one stage of a complicated process in the history of these rocks if we suppose that the matrix was never anything other than colloidal silica. On the other hand, it is not easy to see why, very soon after the carbonate had crystallised out, it should have been

pseudomorphed by silica. It is difficult to envisage the replacement as taking place after the rhombs were encased in chert ; it is relatively easy if the replacement was effected while they were suspended in colloidal silica.

These chert pebbles have proved a fascinating, and, to the writer at least, a fruitful study. Numbers of problems remain unsolved, largely because one is deprived of the evidence of the field-relations of the parent rocks. However, there still remains a wide field of investigation and several types of structure have been noted, but must await further study before their description is attempted.

A Note on Palaeozoic Radiolarian Chert Pebbles found in the Wealden Series of Dorset

By KENNETH P. OAKLEY, Ph.D., F.G.S.

Character and Provenance of the Cherts

AMONGST the pebbles from the Wealden Series submitted to me by Dr. J. F. Kirkaldy for report are several which have proved to be radiolarian cherts. These occurred at three localities : at Steeple (one specimen), Durdle Door (two specimens) and Dungy Head (two specimens). Sections of these specimens have been deposited in the Geology Department, British Museum (Nat. Hist.), where they are registered under the numbers PR.14—18.

In thin-section these cherts exhibit a cryptocrystalline ground-mass, pale brownish in colour, and generally rather turbid on account of minute brown or black inclusions. The cherts are practically free from veining or shattering. The radiolarian tests, which occur scattered through the ground-mass, have been filled with clear, microcrystalline, or sometimes cryptocrystalline silica. Occasionally the structural details of the test have been preserved, but the majority of the radiolaria in these sections are merely represented by obscure casts, all the finer structures of the test having been obliterated by recrystallization.

The cherts can be matched closely as regards their microscopic structure with radiolarian cherts in the Codden Hill Beds of the Lower Culm Measures of Devon, Cornwall and Somerset (Hinde, 1895). They are rather paler in colour, but this may well be the result of leaching in the course of aqueous transportation. Although none of the radiolaria can be identified specifically, the generic assemblage, so far as it is determinable, is consistent with a Carboniferous age.

Description of Sections

Only three of the sections merit separate description :

Slide PR.14. From a pebble of chert found in Wealden Grit, Dungeness Head, near Lulworth, Dorset. Fine-grained, pale-coloured and rather turbid ground-mass, with numerous casts of radiolaria, varying in diameter from 50μ . to 150μ . Some of the larger ones may represent species of *Cenosphaera*.

Slide PR.15. From a pebble of chert found in Wealden Grit, Dungeness Head, near Lulworth, Dorset. Microscopic structure similar to last, but some of the radiolarian tests show structural details, including specimens identifiable as *Carpasphaera* sp. and *Acanthosphaera* sp.

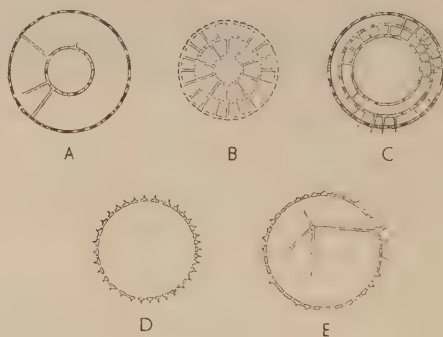


FIG. 26.—SEMI-DIAGRAMMATIC DRAWINGS OF RADIOLARIA IN PEBBLES OF PALAEOZOIC (PROBABLY CARBONIFEROUS) CHERT FROM THE WEALDEN SERIES OF DORSET.

Magnification approx. $\times 100$.

- A. *Carpasphaera* sp.
- B. *Rhodosphaera* sp.
- C. *Thecosphaera* sp.

- D. *Acanthosphaera* sp. a.
- E. *Acanthosphaera* sp. b.

Slide PR.16. From a pebble of chert found in Wealden Grit, Steeple, Dorset. Pale cryptocrystalline ground-mass, full of rounded, light-coloured patches representing the traces of radiolarian tests, and containing some mineral inclusions. Most conspicuous among the latter are small reddish-brown bodies, mainly polygonal in form, and sometimes showing a lattice structure ; they may be pyrite crystals replaced by limonite ; at any rate, there seems to be no evidence that they are of organic origin. Siliceous casts of minute rhombohedral crystals, about 80μ . in length, have also been observed in the ground-mass. They are similar to those found in the Coddan Hill cherts (Hinde, 1895, p. 631), and it is thought that they are pseudomorphs after calcite or dolomite. A small percentage of the radiolarian tests in this

slice have been fairly well preserved. Three genera can be distinguished : *Thecosphaera*, *Rhodospaera* and *Acanthospaera*.

Description of Species represented in Cherts

Order *RADIOLARIA* Müller

Suborder *SPUMELLARIA* Ehrenberg

Superfamily *SPHAEROIDEA* Haeckel

Genus : *CARPOSPHAERA* Haeckel

Carposphaera sp.

Fig. 26, A

Material : One specimen, PR.15b.

Description : Test consists of two concentric latticed spheres united by a number of radial beams, only two of which are completely preserved in the section. Diameter of extracapsular sphere, 168μ . ; diameter of medullary capsule, 56μ .

Genus *THECOSPHAERA* Haeckel

Thecosphaera sp.

Fig. 26, C

Material : One specimen, PR.16c.

Description : Test consists of three latticed spheres joined by two sets of numerous, fine, radial beams. The spacing of the beams seems to be uneven, but this may be accounted for partly by the irregular preservation of the test. Locally the beams project beyond the extracapsular sphere. Diameter of outer sphere, 154μ . ; of middle sphere, 126μ . ; of inner sphere, 98μ .

Remarks : In the relative proportions of the spheres, this form recalls the species recorded in the Edale Shales (Lower Namurian) of Derbyshire (Pulfrey, 1932, p. 194, fig. 16, no. 10).

Genus *RHODOSPHAERA* Haeckel

Rhodospaera sp.

Fig. 26, B

Material : Two specimens, PR.16a, b.

Description : Specimen *a* (Fig. 26, B) is the better preserved test. The two extracapsular spheres are separated by numerous, regularly spaced, fine, radial beams, alternately penetrating to the wall of the medullary capsule. In section, 20 radial beams occur between the extracapsular spheres, 10 of which are connected with the medullary capsule. Diameter of extracapsular spheres, 126μ . and 80μ . ; diameter of medullary capsule, 30μ .

In specimen *b* (not figured) the alteration of short and long beams observed in specimen *a* is not constantly maintained ; thus

occasionally two short extracapsular beams appear between a pair of medullary rays. Diameter of extracapsular spheres, 140μ . and 95μ . ; diameter of medullary capsule 20μ .

Remarks : This genus has not been recorded from the English Culm, but it is known from equivalent beds in the Harz and in Sicily (Rüst, 1892, pp. 137-8). Actually the present form recalls, but not very closely, a species described from the Upper Devonian Mangankiesel of the Harz, namely *R. devoniensis* Rüst (1892, p. 137, Pl. vii, fig. 10). However, the radial beams are more numerous in that species than in the present one, which may be new.

Genus *ACANTHOSPHAERA* Haeckel

Acanthosphaera sp. *a*

Fig. 26, D

Material : One specimen, PR.15a.

Description : Single latticed sphere with about 34 sharply pointed radial spines of constant form and length. Diameter of sphere 130μ . ; length of spines 12μ .

Remarks : This is probably closely allied to the species recorded by Demanet (1938, p. 25) from the Uppermost Visean of Dinant.

Acanthosphaera sp. *b*

Fig. 26, E

Material : One specimen, PR.16d.

Description : Single latticed sphere with four or more delicate radial beams originating from an eccentric point within and extending to the inner surface of the boundary wall. The outer surface of the wall apparently bears short radial spines ; but these are only preserved locally. Diameter of sphere 150μ .

Remarks : Although the spinose character of the test is obscure, the eccentric origin of the internal rays seems to support the reference of this form to *Acanthosphaera*, rather than to *Stigmosphaera*, in which spines are absent and the internal rays united at a central point.

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MECHANICAL ANALYSIS OF THE LOWER GREENSAND OF NORTH-WEST SURREY

By H. S. ROGERS, A.R.S.M., B.Sc., and J. A. RICHARDSON, A.R.C.S., D.I.C., Ph.D., F.G.S.

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I. INTRODUCTION

BETWEEN 1934 and 1936, the authors surveyed on the scale of six inches to the mile, some 52 square miles of the north-west Weald around Thursley, Witley, Binstead and Bordon on the borders of Surrey and Hampshire. This area is covered by the 6-inch O.S. Sheets, Surrey 37 and 38 N.W. and S.W. ; Hampshire 36 and 37. A report on this work was read before the Association in January, 1937, by Dr. J. F. Kirkaldy, as both authors were then abroad. The full report has been lost during the war years, but the notes of the laboratory work carried out in conjunction with the survey have been preserved. As it is most unlikely that either author will have the opportunity to re-survey the area mentioned above, the results of the mechanical analysis are offered as a contribution to our knowledge of the sedimentary petrography of the Lower Greensand. A locality map of the area under discussion has already appeared in a recent paper of one of the writers [1*] ; for this reason no map is included in the present communication.

Our best thanks are tendered to the authorities of the Bessemer Laboratory, Royal School of Mines, for laboratory facilities provided there, and to Dr. Kirkaldy for reading and criticising the paper.

II. MECHANICAL ANALYSIS OF THE SEDIMENTS

Kirkaldy, describing the late Mr. Frank Gossling's work on the Lower Greensand outcrops of parts of Surrey and Kent [2], has recently stressed the importance of mechanical analysis in the stratigraphical investigation of the Lower Cretaceous sediments of the Weald. The present authors support Kirkaldy's contention that mechanical analysis, intensively applied, can be of great assistance in recognising the several lithological units of the Lower Greensand, and in delimiting the lateral variables of which they are each composed.

The results of all the analyses carried out by us in 1936, together with the calculated values for the equivalent grade and the grading factor of each sample, are given in Table I. This Table, as submitted, contained 16 columns giving the percentage, usually

* For List of References see p. 269.

to the nearest unit per cent, retained on I.M.M. Standard Wire Mesh Sieves ranging in number from —150 to +5. For easier reference and to save printing, these results have been recalculated by Dr. Kirkaldy into the six grade sizes used in other Weald Research Committee publications. The complete table is held by the hon. secretary of the Weald Research Committee and is available for reference by anyone interested. Owing to the unavoidable inaccuracies inherent in sieve analyses, the results have generally been approximated to the nearest unit per cent.

TABLE I.—MECHANICAL ANALYSIS OF THE LOWER GREENSAND OF NORTH-WEST SURREY

Locality	1	2	3	4	5	6	7	8
UPPER FOLKESTONE SANDS.								
<i>Pebble Beds.</i>								
Junction of Thursley and Portsmouth Roads	18	31	24	8	9	10	.650	.142
Thursley Rd.	10	32	34	5	9	10	.655	.084
E. of Lion's Mouth, Frensham Common	7	18	32	24	17	2	.580	.283
E. of Great Pond, Frensham	4	23	59	4	2	8	.490	.204
W. of Frensham Common	3	11	50	18	10	8	.640	.330
"	5	10	29	14	21	21	1.210	.339
"	1	12	31	21	24	11	.830	.403
"	2	22	55	12	7	2	.480	.521
<i>Coarse Sands.</i>								
Devil's Jumps, Churt	5	10	55	26	3	1	.495	.619
Cricket Ground, Thursley	12	40	38	4	6	—	.340	.471
"	10	40	39	6	3	2	.380	.313
Thursley Road	9	41	40	3	5	2	.400	.407
Claremont House, Frensham Common	4	15	62	18	1	—	.375	.637
W. of Kettlebury	3	10	50	27	10	—	.552	.411
The Leat, S. of "Dye House," Thursley	17	29	35	15	3	1	.335	.415
E. end, Great Pond, Frensham	3	9	53	29	2	2	.518	.551
W. of Frensham Common	5	27	61	6	1	—	.330	.588
"	4	12	64	16	3	1	.440	.575
"	5	16	49	23	6	1	.490	.535
"	4	24	50	19	2	1	.470	.511
<i>Medium Sands.</i>								
Junction of Thursley and Portsmouth Roads	25	39	36	—	—	—	.215	.428
Red Lion, Thursley	7	61	32	—	—	—	.222	.676
"	18	76	6	—	—	—	.176	.660
Cottle's Garage, Thursley	2	44	52	2	—	—	.250	.667
S. of "Lane End," Frensham	1	21	63	15	—	—	.365	.618
W. of Frensham Common	8	79	13	—	—	—	.210	.732
"	12	33	43	12	—	—	.340	.461
"	2	15	76	7	—	—	.390	.448
LOWER FOLKESTONE SANDS.								
E. of "Pride of the Valley," Churt	17	73	10	—	—	—	.177	.648
S. " " "	15	77	8	—	—	—	.165	.657

Locality	1	2	3	4	5	6	7	8
Near Kettlebury ...	4	85	11	—	—	—	.212	.850
Lane S.E. of "Dye House" ...	20	79	1	—	—	—	.125	.662
Cricket Ground, Thursley ...	12	87	1	—	—	—	.180	.757
N. of Crosswater, Beaufort House ...	2	15	77	6	—	—	.349	.743
Between Thursley and Frensham ...	11	68	20	1	—	—	.195	.595
" " " " ...	9	88	3	—	—	—	.162	.762
" " " " ...	8	49	43	—	—	—	.230	.717
" " " " ...	13	83	4	—	—	—	.170	.727
" " " " ...	8	66	26	—	—	—	.210	.745
Bordon Area ...	6	90	4	—	—	—	.175	.790

UPPER PUTTENHAM BEDS.

French Hill (iii)...	19	61	20	—	—	—	.175	.581
Thursley Area (ii) ...	9	68	23	—	—	—	.246	.784
Churt Area (i) ...	9	77	14	—	—	—	.180	.700

LOWER PUTTENHAM BEDS.

Coarse Type

E. of Stock Farm ...	3	18	56	19	4	—	.400	.581
" " " " ...	4	26	52	13	2	1	.430	.419
E. of "Squirrel's", Churt (iii) ...	3	31	57	6	3	—	.325	.497
" " " " (i) ...	6	33	45	12	4	—	.384	.537
Cemetery Pit, Milford ...	3	20	60	13	4	—	.399	.560
" " " " ...	5	23	56	10	4	2	.420	.436

Fine Type.

E. of Squirrel's, Churt ...	4	35	47	14	—	—	.322	.600
" " " " (iv) ...	10	32	52	6	—	—	.250	.573
" " " " (v) ...	10	56	34	—	—	—	.265	.604
" " " " ...	3	49	37	11	—	—	.280	.595
" " " " (ii) ...	13	54	30	3	—	—	.240	.586

BARGATE BEDS.

Coarse Type (Eastern).

E. of Stock Farm, Hindhead-Churt Road ...	11	22	35	19	11	2	.533	.367
Jump's Estate, N. of Wood Leigh ...	21	67	5	4	3	—	.202	.458
Cosford (v) ...	11	22	34	21	8	4	.521	.414

Fine Type (Western).

Greenway's House, Tilford Road (iii)	14	51	35	—	—	—	.220	.618
Larby's (West's) Pit, Hindhead-Churt Road (i) ...	11	81	7	—	—	—	.170	.728
Larby's (West's) Pit, Hindhead-Churt Road (ii) ...	9	72	19	—	—	—	.215	.718
Larby's (West's) Pit, Hindhead-Churt Road ...	7	33	60	—	—	—	.240	.571
Churt ...	13	42	45	—	—	—	.206	.700
" (iv) ...	6	31	63	—	—	—	.285	.691

UPPER HYTHE BEDS.

Hindhead Golf Course, 7th Green ...	9	70	19	2	—	—	.210	.673
" " " " ...	9	41	42	5	1.5	1.5	.418	.545
Woodcock Bottom, Upwey House ...	7	45	48	—	—	—	.260	.615
Woodcock Bottom, near Dicken's Farm ...	6	56	38	—	—	—	.239	.473

	Locality	1	2	3	4	5	6	7	8
Woodcock	Bottom, near Dicken's Farm	16	40	44	—	—	—	.215	.539
Hindhead	Golf Course	15	83	2	—	—	—	.162	.742
"	" " " " " "	12	86	2	—	—	—	.217	.744
Portsmouth	Road, near Hindhead	12	40	48	—	—	—	.236	.648
"	" " " " " "	9	35	56	—	—	—	.260	.696

LOWER HYTHE BEDS.

N. of Holman Grove ...	...	...	10	60	26	—	—	—	.212	.674
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1. Clay and silt grade (diameter less than .1mm.).
2. Fine Sand grade (diameter less than .25mm.).
3. Medium Sand grade (diameter less than .50mm.).
4. Coarse Sand grade (diameter less than 1.0mm.).
5. Very Coarse Sand grade (diameter less than 2.0mm.).
6. Small Pebble grade (diameter greater than 2.0mm.).
7. Equivalent Grade in mm.
8. Grading Factor.

The Roman figures in brackets after the localities of certain specimens from the Upper and Lower Puttenham Beds and the Bargate Beds refer to the histograms on Figs. 27, 28, 29, the histograms being numbered in each case from left to right. The histograms for the Hascombe area are taken from [3].

(1) Hythe Beds

The Hythe Beds of north-east Hampshire and north-west Surrey are divisible into (a) Lower fine sands and (b) Upper fine-medium sands containing cherts and cherty sandstones. Their lithology thus maintains the generally distinctive features noted by Kirkaldy around Hascombe [3], by Gossling between Brockham and Godstone [2] and by the writer around Albury, Shalford and Blackheath (unpublished observations submitted to the W.R.C.).

(a) *Lower Hythe Beds*.—Silty fine sands and sandy coarse silts, typically coloured buff, pale greyish-yellow or brownish. Locally, impersistent seams, lenticles and ragged crumpled films of lilac, grey and purplish clay and silt occur parallel with the bedding of the fine sands near their base below the Lower Greensand escarpment west of Witley. These clay galls and laminae show the disruptive effects of current action.

(b) *Upper Hythe Beds*.—Essentially silty fine-medium sands, of which the equivalent grade averages 0.25mm. They are moderately to well graded; the best graded sample analysed contained 90 per cent of material of less than 0.25mm. diameter.

(2) Bargate Beds

They appear in two facies :—

(a) “*Fine Type*,” comprising well-graded silty fine-medium and medium-fine sands whose grading factor may be as high as 0.728. These sands are predominant in the west around Green Cross, Churt and Headley.

(b) "*Coarse Shelly Type*"; badly graded, silty medium-coarse sands containing scattered pebbles of lydite, quartz and ironstone, phosphatic nodules, comminuted shells and echinoid plates. Pebbly sand from Stock Farm Pit, east of the Hindhead-Churt Road, has an equivalent grade of 0.533mm. and a grading factor of only 0.367. The coarse facies is developed between Stock Farm Pit, Thursley and Hascombe.

(3) Puttenham Beds

As in the Hascombe area farther east [3], the Puttenham Beds between Thursley, Churt and Headley can also be sub-divided into a Lower and an Upper group.

(a) *Lower Puttenham Beds*.—They comprise two facies comparable with those recognisable in the Bargate Beds.

(i) "*Coarse (Eastern) Type*"; found in the east towards Thursley. They are rather poorly graded fine-medium sands containing considerable percentages of coarser material. The equivalent grade varies between 0.325mm. and 0.430mm. and the grading factor between 0.419 and 0.581.

(ii) "*Fine (Western) Type*"; developed in the west around Churt, Green Cross and Headley. These are fairly well graded medium-fine sands with an equivalent grade of 0.240mm. to 0.322mm., and a grading factor of 0.586 to 0.604.

(b) *Upper Puttenham Beds*.—Essentially well graded silty fine sands partaking more of the characters of the overlying Lower Folkestone Beds than of the Lower Puttenham Beds. They are evidently a transitional facies between the coarser sands of the Lower Puttenham division and the silver sands and fine sands of the Lower Folkestone Beds.

(4) Folkestone Beds

The Folkestone Sands were examined in numerous good sections over a wide area of heathland between Thursley, Frensham, Churt and Bordon. They are separable broadly into (a) a Lower group of fine sands equivalent to the silver sands described by Gossling from the Reigate area [4] and (b) an Upper and more variable group.

(a) *Lower Folkestone Beds*.—Well graded silty fine sands with an equivalent grade of 0.125mm. to 0.349mm.; it averages about 0.180mm. Their grading factor lies between 0.595 and 0.850 and averages 0.750. Seams and lenticles of silt and clay much disrupted by current action, present near the base of these sands west of Frensham, were presumably laid down between tides.

(b) *Upper Folkestone Beds*.—Their lithology is variable and they consist largely of pebbly sands with numerous pebble beds.

- (i) *Medium Sands* : poorly and irregularly graded to moderately well graded fine-medium sands with variable amounts of coarser material.
- (ii) *Coarse Sands* : badly to fairly well graded medium-coarse sands of equivalent grade varying between 0.330mm. and 0.552mm., and grading factor between 0.313 and 0.637.
- (iii) *Pebble Beds* : badly graded, pebbly, coarse and very coarse sands of which the equivalent grade lies between 0.490mm. and 1.210mm., and the grading factor between 0.084 and 0.403.

III. LATERAL VARIATIONS IN THE LITHOLOGY THROUGHOUT THE AREA

(1) Hythe Beds

The Hythe Beds show remarkably little lithological variation laterally along their strike, and their two major subdivisions persist throughout the mapped area and are maintained over wide stretches of the adjacent country. The conditions of deposition peculiar to each subdivision of the Hythe period clearly remained essentially unchanged over extensive tracts. The occurrence of disrupted seams of clay and silt interleaved with the sands near the base of the Lower group indicates that their deposition occurred within reach of current and wave action ; they may have been formed in near-shore pools and lagoons. Such clay lenticles have not been found in the Upper fine-medium sands. Locally, periodic incursions of coarser material led to the formation of impermanent pebble-beds in the Upper division ; the coarsest sand sieved contained 7 per cent of material exceeding 1mm. in diameter.

(2) Bargate Beds

The sea presumably became rather shallower in Upper Hythe times and the conditions of sedimentation which then obtained, persisted into the succeeding period during which the Bargate Beds were laid down. By this time, however, a lateral variation in the conditions of deposition had already been established, with the result that two readily recognisable lithological facies were formed. The character of the sands intercalated with the stone doggers of the Bargate Beds thus changes laterally east and west along the strike (Fig. 27). They are predominantly medium-coarse and very coarse sands east of Hascombe, fine-medium sands farther west around this village, pebbly medium-coarse sands at Cosford, and silty-fine-medium sands at Stock Farm Pit. Locally, beds of pebbly coarse sand occur in this pit. Farther west, around Green

Cross, Churt and Headley, they are silty fine-medium or silty medium-fine sands. The finest sample analysed contained about 10 per cent fine sand, 10 per cent silt and clay and 10 per cent medium sand.

This variation in their grade size from coarse in the east to fine in the west, and the concomittent improvement in their grading from poor to moderate or good, together with the prevalent direction of current-bedding from north-east to south-west, all accord with Kirkaldy's conclusions, drawn from a regional study of the

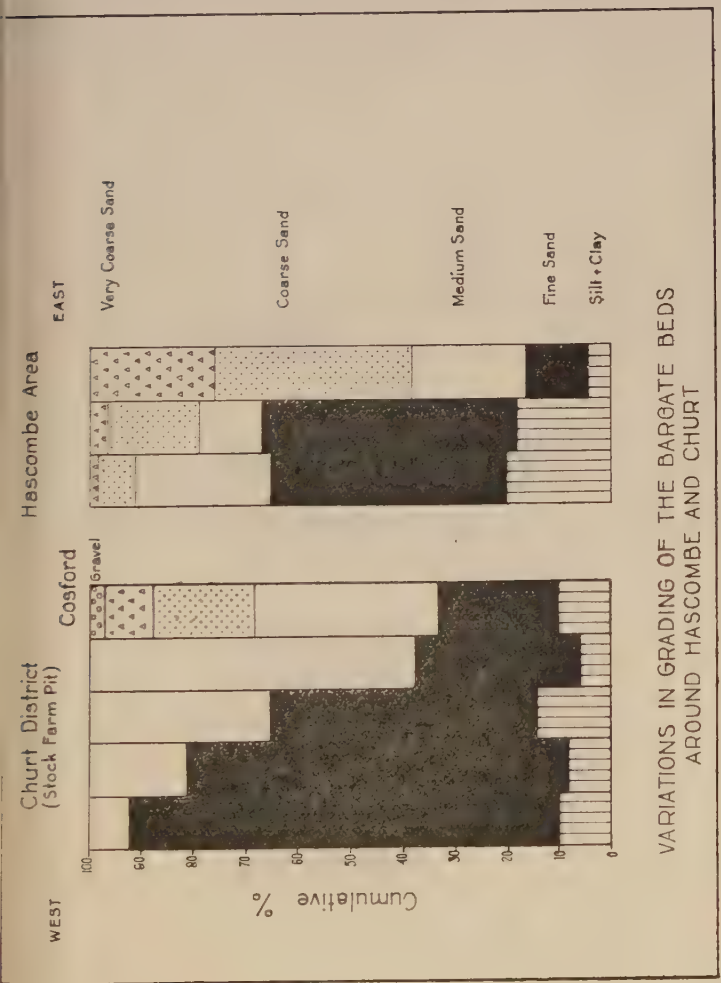
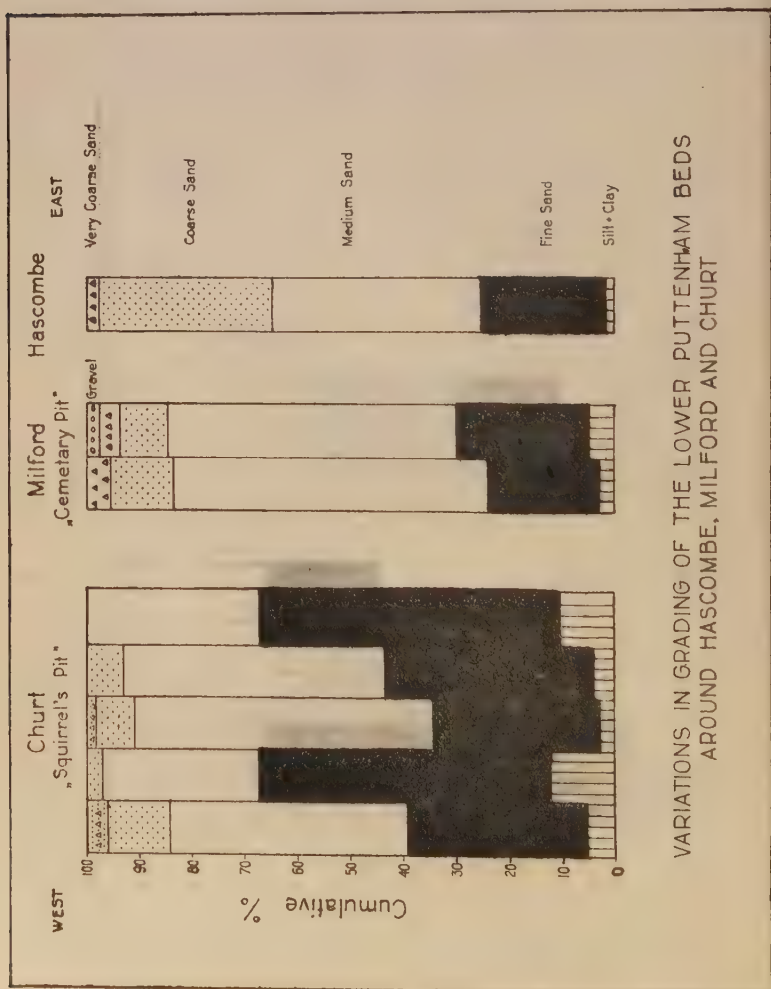


Fig. 27.

Sandgate Beds of the Western Weald, that a shoreline lay north of the present-day Sandgate outcrop, and that the sediments were deposited on a continental-platform shelving southwards and westwards from it [5].

(3) Puttenham Beds

The conditions responsible for the lateral change of lithological facies in the Bargate Beds persisted into the period during which the Puttenham Beds were formed, so that the same general variations are found, particularly in their lower division.



(a) *Lower Puttenham Beds*.—They appear in a coarse facies in the east and a fine facies farther west (Fig. 28). At Hascombe, they are mainly medium-coarse sands; at Milford, medium sands with over 10 per cent of coarser grades and at Churt silty fine-medium sands with small amounts of coarser material. They were laid down on approximately the same platform as the underlying Bargate Beds and under roughly the same range of conditions of sedimentation.

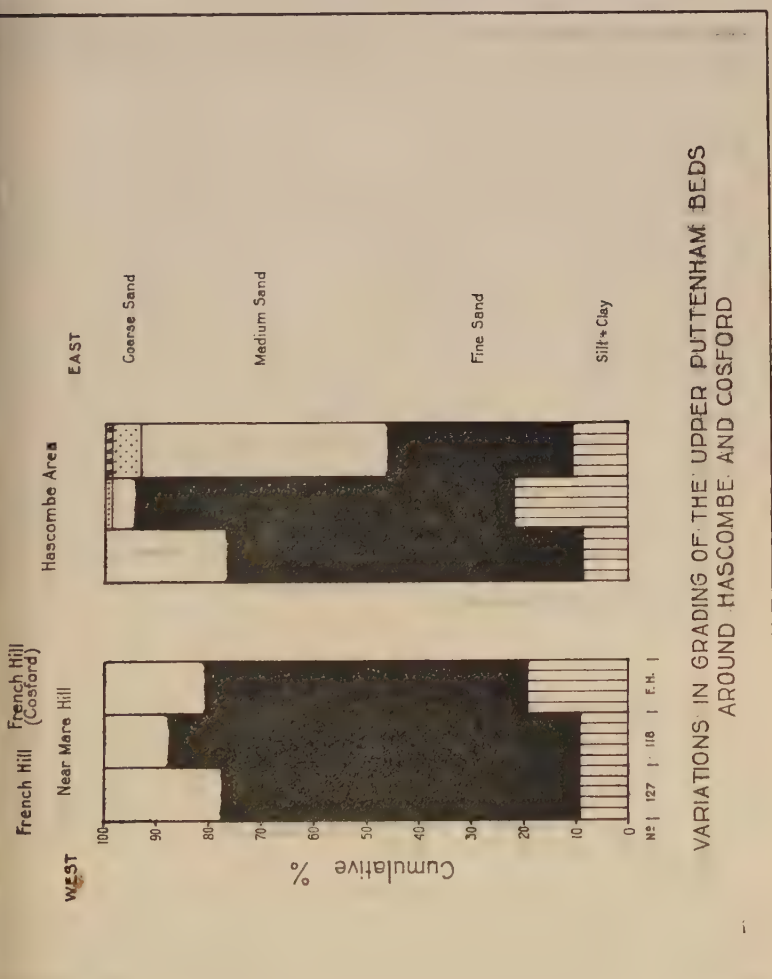


Fig. 29.

(b) *Upper Puttenham Beds*.—The nature of the depositional area had changed by the time the accumulation of the Upper Puttenham Beds began. The difference in slope east and west along the continental-platform upon which deposition was taking place was less pronounced, with the result that the sorting into coarser grains in the east and finer fractions in the west of the material brought down on to it from the old Jurassic land-surface became less complete. The Upper Puttenham Beds (Fig. 29) are essentially silty fine-medium sands between Hascombe and Churt; the small percentages of coarse material present in them around Hascombe are entirely absent farther west around Green Cross and Churt. The Hascombe deposits were thus laid down nearer the old shoreline from which the sea deepened slightly westwards.

(4) Folkestone Beds

The two major subdivisions of the Folkestone Beds persist without pronounced lateral variation of lithology throughout the mapped area and into the adjacent country. There is relatively little difference between the lithological characteristics of the Upper Puttenham and Lower Folkestone Beds; both are essentially silty fine sands. The small variation in grain size east and west along the strike noticeable in the Upper Puttenham Beds is not readily discernible in the Lower Folkestone Beds, however. The Upper Folkestone Beds, by contrast, are markedly different from the sands first laid down. They represent a shoreline facies in which supplies of material exceeding 0.5mm. in diameter were abundant. Thick beds of pebbly sand were thus accumulated, and these contained numerous beds of pebbles. The conditions of sedimentation evidently became less stable and more variable during Upper Folkestone times. Probably the area suffered some slight uplift whereby material, coarser than that supplied hitherto, was brought into the basin of deposition.

IV. CONCLUSIONS

(1) The Hythe Beds of north-west Surrey and north-east Hampshire can be subdivided into a Lower series of silty fine sands and coarse silts and an Upper group of medium sands comparable with those recognised elsewhere in Surrey. Clay galls occurring in the lowermost sands mark a transitional phase between the Atherfield Clay and the normal Hythe Beds.

(2) The sands of both the Bargate and Puttenham divisions of the Sandgate Beds become progressively finer in grain from east to west between the Hascombe area and Churt, a distance of some 12 miles along their strike. This lateral variation in their lithology accords with Kirkaldy's view that a shoreline lay towards north

the present-day outcrop, and that the Sandgate sediments were accumulated on a continental-platform shelving south and west from it.

(3) The broad subdivision of the Folkestone Beds into a Lower group of well-graded fine sands and an Upper group, variable in lithology, containing medium sands, coarse sands and ill-graded pebble-beds, accords with Gossling's observations elsewhere in the Weald.

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FIFTY AND ONE YEARS OF THE GEOLOGISTS' ASSOCIATION

By A. S. KENNARD, A.L.S., F.G.S.

Presidential Address delivered 1st March, 1946

FOREWORD

THE Geologists' Association was founded in 1858 in London by Londoners, and as one of the founders, George Potter, told me, was intended as a mutual help society for beginners. There was but little money then in the science, and every geologist was so born. Hence there was no distinction between "amateur" and "professional," and nearly all the prominent men were men of means and leisure who certainly "got the footings in well." The only "professional" men were the more intelligent of mining managers, a few badly paid teachers, a few dealers and a few museum and Geological Survey officials. To many of these, geology was a "calling"; they were ready to accept a precarious living for love of the work, and no one ever chose geology as a lucrative career. All geologists were welcome as members, and our third President, Prof. J. Tennant (1862-64) combined the teacher and the dealer, whilst from 1873 to 1881 there was a succession of five "professional" presidents, and I feel sure that it was due to them that the Association did not peter out, for there were obvious signs of this in the late sixties. Be that as it may, the Association was founded by a group of young men who wished to know more about the subject and, in particular, the names of the fossils they collected. As George Potter told me, the Geological Society was too stiff and formal, and was above them. They wanted a friendly society with as little formality as possible.

To appreciate the growth and success of the Association, one must know the background of that much abused Victorian period, and that is very difficult for the present generation. It is not to be obtained from novels, for novelists want "copy" and "characters" and the ordinary citizen is of little use as either. I have yet to hear of a novel where the hero or the villain was a geologist. They are just part of that vast body of sober, law-abiding citizens who are the backbone of the country. So I will endeavour to sketch in the background of the Victorian period, in which there was but little change until the advent of the internal combustion engine.

London was then much smaller and, except along the river, a four-mile walk from the City brought one to fields, hedgerows and even tilth. Hampstead was a happy hunting-ground for field naturalists, and remained so until the L.C.C. "improved" it; Burnt Ash Hill, Lee, a paradise for numerous bug-hunters; rooks

still built at the foot of Haverstock Hill and in the City and the finest celery was still grown at Deptford. I may add that peewits nested regularly every year up to 1915 at Catford on ploughed land. At Hampstead, some of the freshwater mollusca owed their presence to "planting" by aquarium dealers, for the faunules were not those of closed ponds. Aquaria were a common feature in houses in those days. London 50 years ago was very different socially from what it is today. One did not see so many persons of obvious alien origin as now. The people were far more friendly, and neighbours were true neighbours and help was freely given. The Working Men's College, where our Association was founded, was built and maintained by private effort. The B.B.C. and the cinema did not exist, people had real homes where they lived and were thrown on their own resources for recreation, and they turned to music, handicrafts and science. As for science, it was the "Golden Age," especially for natural science. Collectors of all natural history objects were common not only in the middle class, but also amongst the "tradesmen," who largely favoured Lepidoptera. The workers in the north of England were famous, and even some of the peerage had important geological collections. Local natural history societies and clubs existed and flourished in all large towns and in some of the smaller places, and were often associated with the local chapel, where their meetings were held. There was, for example, a Wesley Natural History Society with branches all over England, which, under the able guidance of Dr. Dallinger, published a monthly journal, *The Wesleyan Naturalist*. It is true that they were often one-man shows and in time petered out, but they published, and no library has anything like a full set.

Fifty years ago there was a far greater demand for scientific information, and it was catered for by the daily Press, numerous popular journals and by many semi-popular periodicals of which the most important was *Science Gossip*, ably edited by Dr. J. E. Taylor. We know far more than our forebears, but the average level of intelligence is lower. For example, a little while ago a London daily newspaper published the following: "The barometer rose in most places above freezing point." Our own subject, geology, occupied a better position than the other sciences. Leading geologists had a very high status in the intellectual world and were listened to with respect even when they wrote on subjects outside their own particular sphere. We have no Huxley today. Leading reviews such as the *19th Century*, the *Contemporary* and the *Fortnightly* published purely geological articles, and the respective editors must have known what their readers wanted. Semi-religious journals, like the *Leisure Hour* and *Good Words*, published geological papers in a more popular form and much of Sir A. Geikie's work appeared in the latter, written in good English, of which he was such a master. I have heard young men sneer at

Geikie and Hugh Miller as "journalists turned geologists." I wish we had more of that type, for they could write in language not besprinkled with needless foreign words. Their works had a very large circulation over a number of years, and their influence was very great. In the case of Miller, his books were sent to America in sheets and published there. How many semi-popular English geological books are published there today? Scientific jargon, unintelligible except to a limited circle, is a hindrance to those whose only interest in geology is intellectual. We had the *Geological Magazine*, whose columns were open to all, and a perfect storehouse of facts and theories. Its many volumes will always remain a monument to that true old English gentleman, Dr. Henry Woodward, our President, 1873-75, who did so much to help the younger generation of his time. Did not the greatest art critic of the day, John Ruskin, contribute to its pages a series of articles on agates, the illustrations to which have never been equalled? I know nothing of the subject, but I was told that his views, though scorned at the time, are very near to modern views. It was certainly the "Golden Age" for collectors, for the steam navvy and the grab were never seen, and all digging was done by hand. The diggers were not overpaid, and they saved everything that might bring the price of a "pot" (not of tea), for they were thirsty souls. The "Chalkies," i.e. the chalk diggers, had keen eyes, and a visit to a chalkpit then with a little small silver meant a heavy load to bring home. It may be noted that though only the "river" or the "water" (it is never called the Thames) separates the Kentish from the Essex chalk holes, as the men called them, yet it was such a barrier that the tools differed. In Kent they used a long, heavy jumper, and in Essex a short one with a handle. It did not matter what excavation you went in, if there were fossils the men had them safely hidden, as a rule in caches, which they called "tots," a word of which I cannot trace the origin. The famous Whitechapel rag-and-bone merchant, James Smith, was always called "Totty Jimmy" and we owe much of our knowledge of early London to him. All the money so obtained was usually pooled, though sometimes a man would buy from his mates. There were many wealthy collectors who were quite prepared to pay high prices, and it is known that one chalk collector would buy everything the men had and smash what he did not want. Such is human nature. On the East Coast the fishermen and longshoremen kept a sharp lookout for bones washed out from the receding cliffs, and at Kessingland one man used to plough the foreshore and so obtain bones. At Brighton the fishermen knew all about the "Elephant bed," and 2s. 6d. was the usual price for a molar. Our esteemed member, Mr. A. Wrigley, told me that on his first visit to Alum Bay he got in conversation with the pier attendant, and was told that in the old days visitors often wanted fossils and he collected them, but

for some years the trade had ceased. However, he did produce a very fine *Cardita*, which quickly changed hands.

One well-known pit in the Coralline Crag, the Gomer Pit, was a commercial enterprise. It was originally dug by Charlesworth and was temporary, dug in the winter and then filled in and crops grown. It was by far the richest pit, but one year two men were killed by a fall and since then it has only been re-opened once, by Buckingham, the local dealer, *circa* 1896.

London geologists then had fine sections at their doors: Crayford, Grays, Ilford and Swanscomb for the Pleistocene; Charlton and Lewisham for the Eocene; the chalk at Grays, Northfleet and Croydon. It would be a long list that would include all the available sections, for railway fares were low; 1s. 6d. return to Gravesend, 2s. 6d. to Brighton and 5s. to Ipswich. One could collect fossils and study the formations at little cost. There was an excellent institution, the London Geological Field Class, which ran for a number of years under the care of Prof. H. G. Seeley, who, from his slow speech, was usually called "Drops of Wisdom." Many of our early members were trained in this class and their *Handbook*, written by the members, is still very useful, though many of the sections are gone. There was far more hospitality, and "open houses" on Sunday evenings were common. The hosts, not always wealthy men, would welcome all and sundry so long as they had similar interests. Beginners were particularly welcome and refreshments were provided, sometimes on a lavish scale. Those who had broken the code of conduct were barred, and the code was high, but there was little, if any, snobbery.

There has been a marked decline in humour. To laugh at oneself is the best test of humour, and geologists certainly did this. They were well supported by those outside the circle, and "Pre-historic Peeps" in *Punch* by that clever but mannered artist, E. T. Reid, were very popular. Calendars and picture-postcards on similar lines had a ready sale. Eminent geologists were caricatured by Spy in *Vanity Fair*—a great honour. His well-known portrait of Ray Lankester, which caused such a furore at the time, now requires an explanation. The picture of the Professor gazing at a stuffed toucan, with an enormous beak, conveys nothing to the present generation. Just previous to its publication, Lankester had figured in a London police court case, so he is represented as being "before the beak."

Worthington G. Smith and Sherborn were clever caricaturists, and I am fortunate enough to possess a number of examples by the latter, including two on a Council meeting of the Association. The object of the meeting was "what to do with our extensive library." Only the older members can really appreciate these. None of Sherborn's work was ever published, but some of Smith's were lithographed and circulated. There is a fine caricature by him in

the archives of the British Museum (Natural History) entitled "The Dirty Water Medusa," but it belongs to the past, for the very unpleasant controversy in which Ray Lankester was involved is forgotten, though the blank pages in the *Proceedings of the Royal Society*, with only the title, will always remain for the curious to ask "what it means?" It is not altogether true that "the evil that men do lives after them," for as a rule it remains only in tradition and this is forgotten. I was reminded of this the other day when I read an eulogy of the work of Boyd Dawkins. Dawkins was the paid assistant of Hugh Falconer, possibly one of the finest Palaeontologists we ever had, who died suddenly leaving a vast amount of unpublished work, afterwards published in two thick volumes. Falconer's papers were the source on which Dawkins drew, and since they were imperfect his conclusions are often wrong.

Geological dinners provided a good opportunity for humour, and from early times the menus have added to the atmosphere. Those of the Palaeontographical Society in the seventies are very clever and, if rumour is to be believed, the tradition has been maintained by our own Weald Research Committee, though in abeyance owing to present conditions. Humorous verses have always been a marked characteristic of geologists from the earliest times, when *King Coal's Levee* and *Baron Basalt's Tour* were published. Since then many more or less poetic effusions have been written and quite a number have been printed. Those sung at the dinners of "Ye Old Red Lion Clubbe" were often very clever, especially those by that genius, Edward Forbes. Some of these were reprinted in Daubeny's *Fugitive Poems*, 1869. Several appeared in *Science Gossip*, and the author was given as "A Conifer." The late B. B. Woodward told me that he could not ascertain his identity but he was a clever versifier and a good geologist. The *Geological Survey* has always carried on the traditions of Edward Forbes, and many of their songs are preserved in MS. in *The Book of the Royal Hammerers*, and some have been published by Daubeny. The Eolithic Controversy produced a crop and a number were printed. Some are quite good, especially those by our member, Sir Edward Harrison. I am told that there are a number in our archives, but these I have not seen. A volume containing the pick of these would, I feel sure, have a ready sale amongst our members, and it should include the famous "Calveras Skull" which, however, is American. One can often get a good laugh from the restorations of extinct animals, but only geologists can appreciate these.

Many stories could be told about collectors and their treasures. A retiring governor of Portland offered his collection of fossils from the quarries to the British Museum (Natural History). When the official from that institution arrived the donor said he was sorry, but his finest specimen, a fossil fish, had been stolen, but he still had a photo. of it. On seeing this photo. the official remarked,

"We have had this in our gallery for some years. It came with the 'Blank' collection." It is told of a well-known Oxford Professor that when his pupils brought him specimens to name, he always threw the best out of the window with the remark "this is no good," these specimens being retrieved later.

When one remembers the adventures of small and even large collections, one is inclined to think he was right. Fossils rarely have an aesthetic appeal and too often have been dumped on a rockery or helped to form the hard core of a new road. But for the accidental presence of R. W. Hooley at an auction, the A'Court Smith Collection of fossil insects would have been lost. He bought the containing cabinet and its contents because he wanted the cabinet and it was not until he took some specimens to the British Museum (Natural History) where they were recognised, that he realised what a treasure he had saved. It was only by chance that I saved the Brady Collection of Pleistocene Mollusca, for the cabinets had been sold to a local shopkeeper as shop fittings and the contents were included.

No one knows where the Arthur Bott Collection is. This contained several figured specimens, clearly misnamed. Bott was a well-known early officer of this Association and died in 1901. No man did more to salvage important collections than our benefactor Sherborn. Of these the most important was the Pennant Collection preserved untouched for 100 years.

Thus far I have tried to sketch the background of the Victorian period, in which this Association was founded and grew to maturity, and in which my younger days were spent, but a knowledge of this is necessary to appreciate at its true value how our forebears lived and worked. Of the imperfections and omissions, I am only too conscious and I trust I may have my readers' indulgence. There have been far greater changes in the last 40 years than in the previous 150. Until the advent of the internal combustion engine the changes were slow and imperceptible except over a long period. But this engine and two wars were the causes of vast and rapid changes. It is only when one sits down quietly and endeavours to reconstruct the past that one realises what a gulf there is between the past and present.

THE GEOLOGISTS' ASSOCIATION

Members will find many omissions in the following lines, partly because my spare time was, alas, limited, partly because the cost of printing is high. I could only attend a few holiday excursions and I had already determined to confine my attention to the Tertiaries. Hence excursions for the study of the older rocks did not appeal to me and I preferred to collect from Pleistocene deposits and so far as geology was concerned, my choice was the right one and I was able to accumulate material that will never be obtained

again. As already noted, there were many amateur societies in my early days and the first geological society I joined was the Society of Amateur Geologists. It was a small society, true to its name, and most of the members were also members of the Association. In fact, it was a nursery for it. It was run on similar lines, but with a smaller subscription and met in the King's Weigh House Chapel in Arthur Street East. Amongst the members were W. J. Atkinson, a prominent member of the Association and our Librarian, 1894-1900, H. Fleck, who succeeded him and retired in 1903, G. F. Harris, H. W. Burrows and W. J. Lewis Abbott. Harris and Burrows are well known to us for we published their important paper on the Eocene Beds of the Paris Basin in 1892, the standard work for years after. It was the first work in which the results of research in nomenclature were used and it caused considerable annoyance to French workers, who naturally resented being taught by two young English amateurs. Harris died quite young and his death was a great blow to Palaeontology. H. W. Burrows, after working at the Mollusca, turned to the Bryozoa and finally ended in Medieval Archaeology. He died a few years ago and it was certainly appropriate that, being a shell man, he lived in Helix Road, Brixton. Abbott was a born collector and I once heard E. T. Newton remark : " He is such a man. Put him in Trafalgar Square and he would find fossils in the granite basins." Alas he was gone when my predecessor began his work on granite, for Abbott would have been a valuable ally. He was a short, stocky man, with a ferocious moustache, nearly always wore a boater in the field and came from a remote part of Essex, the Dengie Hundred. Abbott at first was a frequent speaker at outdoor meetings, defending orthodox religious views, but at one meeting a working man asked some awkward questions based on geology, of which Abbott knew nothing ; so he made up his mind to learn. Wherever he went he found. Living in North London, he worked at the Admiralty section, a new section at Grays and at Highgate Archway, the results being published in our pages ; and at the same time he collected from all the old sections, Crayford, Loampit Hill, Charlton, etc. Removing to Seal House, Sevenoaks, succeeding Prof. H. G. Seeley as a tenant, he worked the Ightham Fissure, shown to him by Benjamin Harrison, the discoverer, and was the first to describe the group of worked flints, now wrongly termed " mesolithic," since this term had already been used by Spurrell for a different group. Prehistorians are very prone to defy the laws of nomenclature and transfer names, thus causing confusion. J. G. Clark has endeavoured to discredit Abbott's work at the remarkable tumulus at Seal. I can only say that I saw the excavations, and collected from them within a week, and Abbott was right. At this time he was taking a class at the Polytechnic and was writing

on agates. Removing to Hastings in 1898, he continued his exploration of the Kitchen Middens there which he had found some years previously. We now know that there has been extensive slipping and that the objects found there date from Early Holocene to Medieval, and depth is no criterion as to age. His later claim to be the discoverer of that enigma *Dinocochlea ingens*, B. B. Woodward is not correct, and the specimens he gave to the British Museum (Natural History) were taken from the excavations without permission.

A holiday at West Runton produced those much-debated "Worked flints from the Forest Bed," though an earlier find by J. Allen Brown had failed to attract attention. Abbott accumulated a large mass of material, the first part of which went to the Tonbridge Museum when he removed to Hastings. His specimens from the Ightham Fissure went to the British Museum (Natural History) and his final collection was shared between the Geological Museum and the Wellcome Institute. He bought the Rupert Jones Collection of Stone implements, including some figured by Lartet and Christy. These are probably in the Wellcome Institute. His claim to have found Diestian fossils on Beachy Head, though doubted for some time, is now known to be correct. Abbott was possessed of great imagination, but little clarity of exposition, and his papers are the worse for it. No one can understand exactly where the specimens came from at the Admiralty section and it is a most important one. He described a mass of fossil ivory as occurring at Grays, but the foreman of the pit was most emphatic that it never was there and I am afraid that his newspaper articles, though amusing, must be classed under fiction. Certainly his discovery of "a nearly complete skeleton of a mammoth" at Grays became, on examination, a few foot-bones. He had an extensive exhibit at the White City (Franco-British Exhibition, 1908), including a complete skeleton of the Arctic Fox from the Ightham Fissure. It was a complete skeleton, but included many bones of the Hare, but that did not matter for no one was any the worse and the exhibit received a high official award. If the stories I have heard are to be believed, in his later years his imagination had complete control. Nevertheless, he did save a vast amount of evidence that would otherwise have been lost and for this we should be grateful.

The Society of Amateur Geologists soon united with the Metropolitan Scientific Association, and amongst the new men were two of outstanding merit, J. W. Evans and J. W. Gregory. The former was our President, 1913-1914, and well do I remember the first council meeting after war was declared in 1914. We had arranged an excursion to Germany and a proposal was made to send a letter of thanks to the intended conductors and this was supported by Evans and others, but H. W. Monckton led the

opposition and after a fiery debate, the letter was not sent. I noticed at the time that several of the academic world did not seem to realise what war meant. Evans impressed me by his wide knowledge and ability, but since he was a rock man, we had little in common. Gregory and I soon chummed up, possibly because I was still in the trade that he had left, and I still treasure the collection of recent shells he made for me in his travels in Cyrenaica. No explorer ever looked the part less than J.W.G. Rather below medium height his appearance did not suggest a strong physique and he always looked over his glasses when talking to you. He would have passed as a clerk or a small shopkeeper, yet we know where he went and what he did. He had a grand memory, a great asset in our science, and was a keen observer, whilst he had no use for theories, preferring to draw his own deductions from the facts ; and he lived and died for science. It was with a deep sense of personal loss that I heard of the tragedy in South America and realised that our friendly disputations over the former course of the Thames had ceased and I should hear his friendly voice no more. The joint Society eventually petered out and their small balance and library were given to us in 1902.

The year 1894 was a memorable one in Prehistory. Discoveries of Palaeolithic implements were being made all over Southern England, and Worthington G. Smith had just published his classic work *Man, the Primeval Savage*, which included an account of his labours at Caddington, where, inspired by Spurrell's work at Crayford, he had by tireless patience reconstructed many of the flint nodules. Always to the fore in these matters, the Association arranged an excursion to Caddington on 26th May, conducted by Dr. J. Hopkinson and W. G. Smith, and this I attended as a visitor. The party was about 50 in number and the weather was not good. We travelled from King's Cross, then often called Battle Bridge, a name now forgotten, in a third smoker which was full, for in those days there was only one smoking compartment on a coach. All my companions were members of the party, but I can only remember J. A. Brown, Dr. Frank Corner, Walter Crouch and E. T. Newton. After the usual introductions, we were soon talking and I mentioned to Corner that I had found microtine remains at Crayford, only we did not use that word ; we called them mice, which is just as good. This was enough ; the fact was passed on to Newton, the beginning of a lifelong friendship and of much kindly help from him. Newton had a commanding appearance, tall, with a fine face, a good head of hair and a full beard, a feature one rarely sees now. He looked and was an English gentleman, and there is no higher rank, and no man ever looked more benevolent or had more friends, and his vast knowledge was at the service of all enquirers. I may add he was a deeply religious man and a cabinet maker by trade. He was practically self-taught, but he

was a born anatomist and palaeontologist. He had no academical honours and under the present system would never have attained the position he did. His elucidation of the Elgin reptiles is a masterpiece, but one must see the original material to appreciate it at its true value.

If one considers what his official work was, one wonders how he did so much, but "'tis dogged as does it." The Geological Survey Museum benefited by his genius for friendship for many of the specimens were given not so much to the Museum as to Newton. He was a constant attendant at our meetings and then any member could be sure of an expert's opinion on his treasures. He was very cautious and did not like describing new species and added but few names to the synonyms, but a long list of "newtoni" will keep him in remembrance. At Luton the party was joined by the conductors, J. Hopkinson and Worthington G. Smith. The former was an early member (1868), a piano manufacturer and one of the founders of the Watford (now the Hertfordshire) Natural History Society. He was of medium height with a sharp pointed beard turning grey, a pleasant smile and was clearly very alert and energetic. W. G. Smith was tall, and in his usual long cloak and wide brimmed hat he resembled the popular idea of an artist, which he certainly was, as a glance at the figures in Evans' *Stone Implements* will at once show. His was a remarkable personality, very reserved, a great field naturalist and a leading authority on Fungi. He was also an expert archaeologist and a good geologist, but so retiring in disposition that his knowledge and friendship had to be sought. His work *Man, the Primeval Savage* is a model of clarity of expression; the illustrations are perfect and the many problems of the Pleistocene, too often passed over and ignored, are stated by one who learnt his geology in the field. He had his own way of dealing with the workmen and never told them what the objects were that he wanted, but told them to save stones of a certain shape. In my experience this is quite wrong. Take the men into your confidence; tell them to what animal the bones belong and excite their interest, and some will quickly respond. But for the kindly co-operation of the workmen at Swanscomb the fine series would never have been obtained, for one skull and the antlers of *Dama clactoniana* were built up from over 250 fragments.

I had one amusing experience at Waggon's pit, Aylesford, the well-known site for Pleistocene bones and flints and, I may add, a classic locality for Early Iron Age relics. When I entered the pit the men were busy digging and screening, and I asked one if he had any fossils. He replied, "Fossils? What are they?" "Bones," was my reply, and he said they did not find any. A second man confirmed this, but a third said, "I think that boy over there has some bits of bone." I tackled the boy, and from a "tot"

he produced some Rhino teeth and I paid him. To my surprise he asked, "Do you want any Elephant molars?" and he produced three from another "tot." His next question was "Do you want any flint knives?" and it was a heavy load I carried away. I could not understand it, but the explanation was simple. After the discovery of the Belgic cemetery, with its valuable relics, the proprietor had ordered the men to hand over everything under penalty of instant dismissal. Hence everything was passed on to a boy who, if he were found out, could easily get another job. It may be noted that the men at Aylesford first found palaeoliths after seeing them in Maidstone Museum.

To return to the excursion. After a very wet ramble we at last reached the classic site, but, alas, a glance showed there had been no recent digging, the sections were obscured by slipping and the two or three workmen who appeared had only a few neoliths not worth taking away, though J. A. Brown, in his enthusiasm, declared one was an Eolith. However, Smith gave us an account of his work showing the position of the best finds and we could appreciate his work. We were all wet through so we went on to a high tea at Dunstable to which we did justice. After which we inspected Smith's Museum, at least those who could get in did, and the party returned to town. On 7th December, 1894, I was duly elected a member.

Of the earliest history of this Association I know nothing, except what I have gathered from its *Proceedings*, but several accounts have been given, notably one by Prof. T. Rupert Jones, "The Geologists' Association: its origin and progress," in 1880 (*P.G.A.*, vol. vii, pp. 1-57). Our early volumes are a storehouse of information, not only on geology, but on the allied sciences, and one can always turn to them with profit as well as pleasure. But there is a problem with the foundation of our Association. George Potter used to emphasise the fact that it was started by a few young enthusiasts for naming and exchanging fossils and friendly intercourse. This may be so, but our first constitution and rules are for a real geological institution. Four vice-presidents would not be required for a friendly "swop." I know that vice-presidents were often looked upon as a source of additional revenue, and one Society had two classes of members, honorary and ordinary, the former paying double the subscription of the latter. Our rules were drawn up for such a body as we now are, and the problem is who was responsible. Nominally a committee, but it is always mainly the work of one man, and I think that Toulmin Smith was responsible. He was an outstanding man and saw the possibilities; the youthful enthusiasts could not have done it. Had it been a mere "swopping" society it would have soon petered out judging from the appeals in the early numbers. As it was, the Association had a normal growth in accordance with its constitution and rules.

There is one original member of outstanding merit who is now forgotten, probably because he wrote so little—John Pickering. W. Topley dismisses him as follows: "Mr. Pickering, a wharfinger in Thames Street, was an early member of the Association and also a constant visitor at Dr. Bowerbank's house. He traded much in oranges and other fruits from the shores of the Mediterranean and took advantage of this to collect shells and other objects of interest from foreign sailors" (*P.G.A.*, vol. ix, 1886, p. 390). Topley had not studied Vol. I of our *Proceedings*, nor the *Q.J.G.S.* I may add that the excellent Survey Memoir on the Weald is usually considered Topley's work. It is true that he was the senior of the team, but I am assured that the greater part of the work was by Drew. Pickering was elected to our Association in 1858 and hence was an original member; he served on the Committee in 1859 and was vice-president from 1860 to 1866, when he retired on account of ill-health. He was alive in 1871, when he lived at 29, Loraine Road, Upper Holloway. Gwyn Jeffreys refers to him five times (*British Conchology*, vol. i, pp. 65, 69, 189, 211, 298), as do Forbes and Hanley (*A History of Brit. Moll.*, vol. iii, pp. 10, 137, 138, vol. iv, pp. 261, 267). In vol. iii, p. 137, Hanley states under *Rissoa anatina* (Drap.) [= *Pseudamnicola confusa* (Frauen)]: "We owe our opportunity of examining the animal to Mr. Pickering, a gentleman well versed in the terrestrial and fluviatile Mollusca of Britain." This from Hanley is very high praise indeed. Pickering was a good field naturalist and carefully studied the ecology of the molluscs he himself collected; it was not a case of "three specimens and a name." Thanks to R. Winckworth, part of his English non-marines are in my custody. They are *ex Coll.* P. B. Mason, and were probably bought by Dr. Mason when Pickering's collection was sold. (I was told that Calvert bought most of his fossils, so these may be in America.) They are a fine series and were obviously collected mostly in the field by Pickering himself. Long before the Association was founded, he was the recognised authority on the Post Pliocene non-marine shells, and his assistance was sought by geologists in naming their finds. Thus he named for Prestwich the Fisherton shells (*Q.J.G.S.*, vol. xi, 1855, pp. 106-7) the West Hackney shells (*loc. cit.*, p. 110) and the Reculver, i.e. Chislet material (*loc. cit.*, p. 112). He is responsible for the Copford list published by John Brown (*Q.J.G.S.*, vol. viii, 1852, pp. 184-193) and the Newbury list of T. Rupert Jones in 1854 ("A Lecture on the Geological History of the vicinity of Newbury," pp. 41-2). Rupert Jones was, I believe, employed by Pickering to help him in the task of picking out specimens from the material. Pickering's first contribution to the literature was in 1847, a short note, "Description of a remarkable species or variety of British *Paludina* (*Zoologist*, vol. v, pp. 1786-7), a colour form of *Viviparus viviparus*

(Linné). The only other papers I can trace are three in our first volume :

1. "On Brickfields, Gravel Pits, Sand Pits, and Peat beds at Copford, Fisherton, West Hackney, Reculvers and Kennet Valley" (vol. i, pp. 78-88).
2. "On the opercula of Recent Gastropodous Mollusca" (*loc. cit.*, pp. 124-7).
3. "On the *Pitharella rickmani*" (*loc. cit.*, pp. 127-8).

The first is an excellent paper and must be read to be appreciated. It is a summary of his previously published work, but he also shows how to detect the shells and, as he says, it is intended for the young student. It is clear that he had never visited Copford, and the material must have been sent by John Brown. Unfortunately there are Early Pleistocene deposits there as well as Holocene, but no distinction was made. It was lucky that in the Geological Survey Museum there was a small box of material from the Pleistocene (Ex. Geol. Soc. Coll.) and one can easily separate them by their condition. In addition, I think Brown had an enemy in his own household, for though it is true that accidents will happen, I cannot believe that he was responsible for the mixture to be found in his material. W. Whitaker gave me a fairly large quantity of Copford material given to him by Brown. This yielded the usual mixture of Pleistocene and Holocene shells and in addition several *Nematurellas* from the Bembridge marls and two I could not place. There is a large box of material in the British Museum (Natural History) and this has a number of "foreigners" in it. I have series of shells from Harwich and Witham (ex. S. P. Woodward Collection) which certainly came from Brown, and there are Grays shells in both. Alfred Bell told me that Brown used to pay the children of the foreman at Copford to wash the material. This will account for part, but not all the trouble. Is it possible that the curious mixture that Brown described from Chislet (*Q.J.G.S.*, vol. xv, 1885, pp. 133-6) is due to the same unknown cause? There were always grave doubts about it. Pickering gave to us some books and many specimens, including on 3rd December, 1860, a series of 50 species from Copford. When our collection was divided between the two national collections this series went to Jermyn Street and is now in the Survey Museum. The shells are mounted on cards and are in the same condition as when they were originally given; and I hope that they will always be kept thus. Allowing for the period, there is only one mistake and that is interesting. In the Copford list of 1852, Pickering listed *Vertigo alpestris* Alder, a record that Jeffreys doubted in 1862 (*Brit. Conch.*, vol. i, p. 260), and suggested that it was an error for *V. pygmaea* (Drap.). The shells labelled *V. alpestris* are really *V. moulinsiana* Dupuy. In 1852 this species had not been detected in these islands, but Pickering

had noted them as a distinct species. He only knew *V. alpestris* from the description, and since both species have four denticles in the mouth, one can understand the mistake. Though he made a mistake in the trivial name, he was the first to detect this shell in England.

It is clear from this paper that Pickering was an excellent field naturalist, a most careful collector and was an expert with Foraminifera and Ostracoda. His second paper is really an introduction to the third, "On *Pitharella rickmani*." Only casts of this species were found at first and these were identified as *Voluta* sp. and the presence of a marine shell in a freshwater deposit is an awkward fact. Better specimens coming to hand, it was described as a Pulmonate allied to *Lymnaea*. Pickering, however, from an operculum found with it, thought it was an operculate allied to *Paludina* [*Viviparus*], an opinion supported by Caleb Evans (*P.G.A.*, vol. i, pp. 336-351). I can now add another contribution by Pickering that should have been printed over 80 years ago. In July, 1861, Pickering and Prestwich visited the excavations for the main sewer across Plumstead Marshes to Crossness and collected a series of shells, and the results must have been communicated to Jeffreys (*Brit. Conch.*, vol. i, 1862, p. 65). Early in 1862, the Association had an excursion there, and on 16th June, 1862, Pickering exhibited a series of fossil shells from the cutting, and presented them to our Museum, but, alas, they have disappeared. Amongst the papers that came to me from my late colleague was Pickering's report on them. The MS. was probably given to B. B. Woodward by Rupert Jones. It is as follows, the modern names being given in brackets.

Shells from the Main Drainage cutting between Woolwich Arsenal and exit to the Thames, July 1861.

Marine. Yellowish sandy clay.

Scrobicularia piperata Rare. [*S. plana* (da Cost)]

Tellina soliduea one valve. [*Macoma balthica* (Linné)]

Peat.

Brackish water.

Rissoa anatina rather plentiful. [*Pseudamnicola confusa* (Frauen)]

Freshwater.

Limneus pereger plentiful. [*Lymnaea peregra* (Müll)]

„ *truncatulus* rather rare. „ *truncatula* (Müll)]

„ *palustris* rather plentiful. „ *palustris* (Müll)]

Planorbis nautileus one specimen [*Planorbis crista* (Linné)]

Land.

Succinea putris abundant [*Succinea elegans* Risso]
the elongated form found probably
on water plants.

Entomostraca not rare probably
two species.

Seen in the Blue Clays.

Anodon cygneus [*Anodonta anatina* (Linné)]

Cyclas lacustris [*Sphaerium lacustre* (Müll)]

The two or three parcels of shells we met with I have no doubt came out of the surface drainage cuttings, not the main drainage, and it is therefore very doubtful if they were really fossils, as I do not find several of the species in the deeper cutting, which may be accounted for by their being such as are usually found in running streams, whereas those in the main drainage cutting are more frequently found in stagnant puddles. Hence it would appear by the entire absence of land shells, except *Succinea* (which cannot live on dry land and dies in the water), that at the time the Mollusca under consideration existed, the place was a boggy marsh, interspersed with pools and puddles of water overgrown with sedge, on which the *Succinea* lived while the *Limnaeaceae* inhabited the water, that an occasional overflow of the brackish water of the neighbouring part of the Thames introduced the *Rissoa anatina* without destroying the *Limnaeaceae* which do not object to live in slightly brackish water. The marine shells which are shallow water species, of course, owe their introduction to other causes and conditions. The shells from the heaps of river sand are foreign to the neighbourhood.

J. Pickering.

It is a great pity that this report was not published, for it is far ahead of any contemporary work, since it was not until some years later that Bourguignat published his work on similar lines. There is one error in Pickering's deductions. There is no need to postulate the overflowing of the river to account for the presence of *Rissoa anatina*. We now know that it is a freshwater species and not a brackish as was then supposed. That is all I can find out about Pickering, but it is sufficient to show that he was a pioneer and received the usual reward of such. As to *Pitharella*, it is still a puzzle. A. Wrigley, than whom there is no better authority, informs me that the correct name of the English shell is *Pitharella rickmani*, Edwards 1860. There is an allied but distinct species in the Thanetian of France, originally described as *Buccinum arenarium* Melleville 1843, and later as *Ampullaria problematica* Deshayes 1862. On the Continent it is now placed in *Douvillea* (Bayle, 1880) as a subgenus of *Actaeonina*, but *Pitharella* has priority. That it is an operculate is certain, but its systematic position is uncertain. Since it is a freshwater form it is unlikely to be allied to *Actaeon* or *Actaeonina*, and it is more likely to be allied to *Viviparus*. An additional locality is in the Woolwich Beds, Worthing (*P.G.A.*, vol. xviii, 1937, p. 49).

On 28th March, 1896, an excursion was made to Galley Hill and Swanscomb Hill and a report was published (*P.G.A.*, vol. xiv, pp. 305-6). The Directors were the President, F. C. J. Spurrell and H. Stopes, and the main object was to examine the section whence the "Galley Hill Man" was obtained. The exact site is on the north side of the Dover Road and just west of the old schools. On recent maps the name Galley Hill Pit is given to an excavation on the south side of the road and east of Galley Hill, which is apt to mislead. The excursion was a complete success and most of the party were able to obtain worked flints, for the site was a prolific one. This was the last time I saw Spurrell, for he had left Belvedere

and gone to Norfolk, but had come up specially for the excursion ; but he did attend an excursion to Knock Mill on 13th June, 1908. Spurrell was a remarkable man, very quiet and very retiring, but he did know, though he published but little, and his work can always be relied on though his conclusions on the so-called "Deneholes" are incorrect. I may add that locally they are always called "chalk-wells," which they are. His principal papers are "Palaeolithic Implements found in W. Kent" (*Arch. Cantiana*, 1883), a most important paper, though overlooked : in it he describes the well-known Baker's Hole flints and their method of manufacture, anticipating the work of Smith and Dewey. "Early sites and Embankments on the margins of the Thames Estuary" (*Arch. Journ.*, 1885), which is the chief paper on the subject. He had plotted all the embankments and enclosures on both sides of the river, and his conclusions as to their age are now accepted, except in "newspaper" science, where they are still spoken of as "stupendous Roman works." His conclusions were, however, anticipated in 1861 (*Once a Week*, pp. 664-9) in an article signed and illustrated by J. W. B., whom I cannot place. "History of the Rivers and Denudation of W. Kent" (Report of the W. Kent Nat. Hist. Soc., 1886). This is another overlooked paper full of facts not to be found elsewhere and sections long since obliterated, "On the Estuary of the Thames and its alluvium" (*Proc. Geol. Assoc.*, vol. xi, 1889, pp. 210-230), which is still the best account. His account of the Palaeolithic working floor at Crayford is well known, and his patience in replacing the flakes has been an inspiration to later workers. He is also responsible for a number of smaller papers, and there are 22 references to his work in Whitaker's Memoir.

A great loss was the non-publication of a paper read before the Essex Field Club, 24th March, 1888. This is described as "a paper on the Essex shore and Marshes of the Thames," largely illustrated with maps, plans and geological sections and treated of the early and later geological changes of the river and its shores, the floods and making of the seawalls in prehistoric times and the early history of the Thames, the advent and remains of the Romans, their potteries, dwellings and burials ; the mysterious mounds near the estuaries, the salt-pans, Weller's works and "Red Hills," the ports, shoreworks, camps (Shoebury and Benfleet), Saxon and later works which many years' researches on both banks of the Thames from London to the Nore had enabled him to note and examine. It was hoped to publish this paper with maps, plans, etc., in an early number of the *Essex Naturalist* (*Essex Nat.*, vol. ii, 1888, p. 52). Alas, this was never done ; why I never could find out. Part was published in 1890. "Camps at Shoebury and Benfleet" (*Essex Nat.*, vol. iv, pp. 150-5), the only published account of these camps, shows how great was the loss to knowledge. Spurrell

was a very good botanist and an expert on most branches of natural history, as his paper on the Thames alluvium shows clearly ; whilst he made many researches on early charters and legal documents and revived the old forgotten name of Ebbsfleet for the stream west of Northfleet. No other area can show such a sequence of Post Pliocene deposits as that valley. "Wellers' works," referred to, is another revival, for Spurrell had discovered that the men employed in salt works when the salt was obtained by boiling were called "wellers," a name made famous by Dickens and obviously derived from the action of boiling water. Late in life he turned to Egyptology and is thanked by Flinders Petrie for his work on some thousands of weights found in Egypt. That one who knew so much published so little will always be a matter of regret, for many of the sections have long disappeared. E. T. Newton once remarked to me : "It is curious that though no one disputes Palaeolithic implements as the work of man, yet whenever human bones are found in the same deposits they are disputed at once, and after all he must have had bones." If ever a find were properly authenticated, it is *Homo swanscombensis*, by our member, A. T. Marston, and everyone must pay him a high tribute for his patience and knowledge in obtaining the second bone, yet even this has been adversely criticised, not openly, but by suggestion. *Homo galleyensis* has been much debated and the published account is not correct, for it would appear that the skeleton was found by one gang of workmen who informed M. Heys of the find and promised to let him dig it out, but it was "appropriated" by another gang, who dug most of the skeleton out and sold it to R. Elliott. Though the evidence is apparently clear that it was found at a depth of eight feet in undisturbed gravel, there are grave doubts as to its age and neither Spurrell nor Stopes would accept it. Complete skeletons do not occur in this gravel, only single bones. It is true that in the lower loam I have on a few occasions found associated vertebrae, but that is all, except that once in the sand there were several bones of a bird close together and probably associated. The depth is too great for an early burial ; those I saw at Milton Street in 1905 were at two to three feet below surface. They were probably Romano-British, but there was no clue as to age and the bones had crumbled to dust before I saw them. I would return a verdict of "not proven." In justice to my old friend, "Matty" Heys, I must protest against the statement that he was not a "trained observer," the implication being that his evidence is not reliable. Heys, like Spurrell, was a born observer, which is much better. He was a schoolmaster and constructed a scale model of Swanscomb Hill with all the prehistoric sites and earthworks marked in, a monument to his patience and observation. The last place I saw it in was the Workmen's Hall at Northfleet. There is one Pleistocene human skull that has never been described. On 7th November, 1902, Gilbert

White exhibited a "Human skull from the Middle Terrace Brickearth of Swanscomb, Kent" (? Pleistocene) (*Proc. Geol. Assoc.*, vol. xviii, p. 96). This came from the tramway cutting below Rickson's Pit and was dug out by the exhibitor from the sludge deposit that covered the working floor at Baker's Hole. It was in the collection of Dr. Frank Corner, and the skull is certainly Pleistocene and should be described.

Prehistory has always been a favourite subject with us. In 1891 Prestwich published his classic on the drift stages of the Darenth, based on the finds of Benjamin Harrison, and soon the Eolithic controversy was waged with needless bitterness. One can now consider them with the help of over 50 years' experience and without the partisan feeling then so prevalent. My mature judgment is that some show human work or usage but their age is uncertain. Over-enthusiasm has, however, been too prevalent, and I cannot see any trace of human work in the Eoliths from Piltdown. There are also grave doubts as to the true localities of some of the later finds. Most of the specimens were obtained from the field workers; and the higher the level the greater the value. Aylesford, that well-known locality for Palaeoliths, is close at hand. There can be no doubt that examples did find their way from Aylesford to the plateau, and the specimen of a rolled palaeolith on which W. Cunnington laid so much stress was one of them (*Nat. Science*, vol. ix, 1897, p. 327).

One thing that I have noticed is that the strongest supporters of Eoliths are the flint hunters, the men who pace the ploughed fields yard by yard, critically examining the exposed flints, whilst most of the chief opponents are the collectors, now nearly extinct, who value them as curios and whose standard of value is the amount of work spent on the specimen. Be that as it may, we held an excursion on 13th July, 1896, to the Kentish Plateau to examine the sites whence the Eoliths had been obtained under the guidance of Lewis Abbott (*Proc. Geol. Assoc.*, vol. xiv, pp. 196-8).

It was a glorious day, and the party eventually reached Fawkham Green—a complete success so far as seeing was concerned, but no member found an Eolith, not even a bad one.

The excavations for two new reservoirs at Tottenham were visited by us on 20th April, 1901, under the guidance (no adjective needed) of W. Whitaker. No man did more to make the Association the success it is than "William." He was a remarkable man, both mentally and physically, for he always "led" the party and there were few aspects of knowledge with which he was not well acquainted, and he was very proud of being a Londoner. Many of us are indebted to him for gifts of literature and specimens, freely given in his pleasant manner. There has only been one "William." His London memoir is a classic and is still the last word on many problems. Written in splendid English, his ready wit is on many

pages, and as you read it you can see the man and hear his voice. His knowledge of geological literature was outstanding, especially in such minor studies as medicinal springs, and many of us are deeply indebted to him for the numerous bibliographies he published, often in the publications of local societies, and thus too often overlooked. Only those who have attempted this work know what labour it entails. He was very keen on organising unofficial excursions to temporary sections in London, of which no report was written. Two of these I attended, one to London Wall and the other to Westminster, and much valuable information was obtained. His long association with engineers was a great asset to us in arranging excursions. I wrote the report of the Tottenham excursion, though it is credited to H. W. Monckton, who did his best to rectify the error. In the report there is reference to a "Viking" ship found there, which figured prominently in the Press at the time and was duly forgotten. It was much later when I heard from the workmen the truth about this "ship burial," for such it was. When found the ship was upside down, in which was clearly an old branch of the Lea (Lee is the official spelling) and since all the objects found near it were medieval, the boat was considered to be of that age. But there was a burial under the boat of a human skeleton, a sword and gold ornaments. The sword was in Dr. Corner's possession and he sold it to Sir Guy Laking, whose collection was sold at his death and it passed to a well-known Italian collector, but where it is now I cannot say. It was an English sword and not a Viking one. The gold ornaments probably went to the crucible, but none of my informants knew, though all agreed as to their presence. One can conclude that it was a Pagan Saxon interment, similar to the cenotaph recently discovered at Sutton Hoo.

One could relate many other traditions as to excursions, how the director lost the party, or vice-versa, and, what is of more importance, of discoveries made on excursions, but time is short.

OUR PUBLICATIONS

To deal with these adequately is beyond the power of one man and would require a thick volume by many authors : for we have much pioneer work to our credit. One subject would I mention is "River Development." It is true that W. M. Davis published his first paper in England : "The Development of Certain English Rivers" in the *Geographical Journal* in 1896, but it received little attention. In 1899 he gave us a lecture on "The Drainage of Cuestas." Its importance was at once recognised, and speaker after speaker asked for its publication, and in due course we published it. Since then his views can be traced in many papers. We can also claim to be the pioneers in subdividing the Upper Chalk ; for in 1870 we published the well-known paper by Caleb

Evans, "On the Chalk between Croydon and Oxted," followed in 1900-1907 by the work of A. W. Rowe and C. D. Sherborn. The plates by H. H. Armstrong are excellent photographs and a pleasure to the eye. We may well be proud of this series of papers, for it is the best work on the subject ; it lacks, however, two things to make it complete—an account of the earlier work and a bibliography. Rowes' first paper on "*Micraster*" was published by the Geological Society after needless acrimony, for which the authors were to blame, for "*Suaviter in Modo*" was not part of their make-up. I was on the Council when a paper was first offered to us and Sherborn told me before the meeting that an attempt to suppress the paper would be made. Our President, J. J. H. Teall (said to be a lazy man, but certainly a born diplomat) took the chair, and it was soon evident that personal feelings were high, but the opposition was not to the paper, but to the dictatorial attitude adopted by the authors, which was so marked as to upset even E. T. Newton and W. Whitaker. However, Teall smoothed everything out in a most delightful way, the paper was accepted for reading, and peace was in the land once more. It was a pleasure when some years ago I was able to salvage some honorary diplomas awarded to Teall from a "junk" shop, and they are now in the archives of the Survey.

Our published work is clear proof of our success, and we owe a debt to the successive editors, especially to the record-breaking G. S. Sweeting, for their labours. We are so used to receiving the parts on time that we are apt to overlook the amount of work that it entails on our honorary officers, and I take this opportunity of thanking them all, past and present, on behalf of the Association. One may well ask why our Association has been a success whilst others have petered out. A study of our *Proceedings* has convinced me that the principal factor has been the excursions. They always produce new facts and good fellowship. One does not get fiery debates on an excursion, though you often do at meetings. Many of our papers owe their existence to projected excursions, and in fact have been written on our request for them. We have always welcomed new ideas and the constant influx of the young and enthusiastic has helped us greatly. We can look back upon our past with pride, and forward to the future with hope.

FINIS

Now as to the future of our beloved Association. We are told by the Jeremiahs that geology is in a bad way ; that it is not so popular as it was and students are decreasing in number. Judging from the literature it has been in that condition for the last hundred years, but when I joined the membership was 541 and now it is over 1,300. Few, if any, Scientific Societies can show such an increase. There are many factors to consider. The novelty of the wonderful new facts as to "prehistoric beasts" disclosed by

geology has worn off and popular imagination is no longer stirred by the discovery of a reptile 60ft. long ; and, as Mark Twain observed after a visit to Professor Osborn (possibly fictitious), "It would have been much longer only the plaster ran out."

Geology was fortunate in that its early exponents were born teachers who could write in plain English and did not use estoeiric terms borrowed from German authors. What a list it is ! Buckland, Conybeare, Edward Forbes, the two Geikies, Huxley, Charles Kingsley, Lyell, Mantell, Hugh Miller, John Morris, Murchison, Parkinson, Phillips, Whewell and others too numerous to mention. No other science can show such a list except possibly anatomy. From 1831 to 1894 no less than 18 geologists occupied the chair of the British Association, but from 1894 to 1931, only five, and of these four were better known for their other work than for geology. On these figures the trouble is at the top. One suggestion is more teachers, but apparently the number of persons interested in geology varies inversely with the number of teachers. After all, teachers are born not made, and many brilliant workers are bad exponents. The late Lord Kelvin was a good example of this. I am told that after five minutes no member of his class could follow him. He had wandered from his subject, as I have tonight, and was working out a totally different problem. I trust the members will not think that I have a poor opinion of the present teachers. We have many excellent teachers, and their students are a credit to them. It is because of this that I am so hopeful of the future. In the beginning, geology was largely theoretical, but the practical side soon asserted itself, and today it is a career and those who follow it are assured of good teachers. Our problem is how can we attract the young and intelligent to the academical side, and here we want popularisers like Mantell, Kingsley and Hugh Miller. Their writings made many geologists and geology is far more fascinating now than when they wrote. We were all beginners once and it is the beginners who need attention. When I was young the leading lights like Dr. C. W. Andrews, W. Whitaker, A. S. Woodward and H. B. Woodward were constantly present at our meetings and their knowledge was always given freely to the coming generation of the time. If we found something we did not know, we always said, "Take it up to the G.A.—so and so will name it for you. He is sure to be there," and in many cases the specimen was given to the Museum whose representative had named it. It is certainly true that one can deduce the character of a "Keeper" by the number of gifts made to his department. The late H. W. Burrows told me that in his early days he was in the Natural History Museum, endeavouring to name some specimens, when Sir Richard Owen came in the gallery. He at once said to Burrows, "Come with me and I will introduce you to someone who can help you," and introduced

him to R. Bullen Newton with the remark, "You must help this gentleman all you can." Owen's personality was very mixed, but this must be placed to his credit. I would place on record how much I am indebted to many officials in both the National Institutions that deal with geology for kindly help, and all students who have sought their help will cordially support me. And I would also admit my admiration of their courtesy whenever they are asked to name a flint cast of an echinoderm or "Is this a thunderbolt?"

Collectors of fossils were the real founders of geology and must be encouraged, since they provide the material for the specialist. William Smith, the father of English geology, was a collector and every palaeontological paper is a tribute to his memory. Large series of specimens, both recent and fossil, easy of access, should be available for comparison so that collectors can name their treasures, which is their great desire. Such formerly existed in the British Museum (Natural History) and Jermyn Street; these exhibits enabled me to get in the "footings" of what little knowledge I have, and I am not alone in this respect. Restricted exhibits, however desirable from an aesthetic viewpoint, are of restricted use. A Scientific Museum is not a jeweller's shop and if so treated ceases to be of any practical value. The architect should have no say in the layout of the cases, and "vistas," however desirable in art galleries, need less consideration in a geological one, where the contents of the cases are the main object. One does not like to see the busts of eminent geologists treated as mere ornaments to a library and placed where no one can really see them, whilst the pedestals on which they were formerly placed, fine examples of polished rocks, are consigned to the basement. An exhibit showing the history of geology from early times to the present day would have a true educational value and a popular appeal as well. Many of our deductions are based on negative evidence. One often sees the expression "does not occur" when the correct phrase is "has not been found," for often the schoolboy comes along and finds it. A course of logic should be included in every worker's education, whether academical or professional. Many of the conclusions one reads are illogical. Mine has been a very limited study and it was quite late in my life when I realised its magnitude and the many problems connected with it, how inadequate was our knowledge and how much there was to learn.

I would take this opportunity to thank the many friends who have helped me in my work, the majority of whom I have met through this Association, and all the members for their kind consideration during my term of office. It was a difficult time, for we were fighting for our existence and for all that we valued, and we saw the end of the battle and the dawn of what we all hope will be a new era. Our outlook on life is governed mainly by our

health and "one cannot be too careful in choosing one's ancestors." I always wear rose-coloured spectacles, a great asset during the last seven years. I cannot write "Ichabod" over our portals, for I still find plenty of people of all ages and conditions who are eager to learn about "our Earth and its story," and I confidently predict that there will always be an England, there will always be plenty of geologists and, if we are true to our traditions, a prosperous Geologists' Association.

"FLOREAT."

THE GEOMORPHOLOGY OF A PART OF THE MIDDLE THAMES.

By ASST.-PROFESSOR F. KENNETH HARE

(Read 6th December, 1946)

I. HISTORICAL INTRODUCTION

THE present paper discusses in some detail the geomorphology of parts of the Middle Thames area. Evidence is presented which bears on the development of the modern Thames drainage system and on the origins of the landscape of the surrounding countryside. The conclusions reached are based mainly on an intensive study of the remarkable belt of drift-covered country that lies north of the Thames between the Wye and Colne confluences, i.e., the country round Slough and Beaconsfield. For a variety of reasons discussed later, this small tract of country constitutes a veritable museum of Thames history; in the words of S. W. Wooldridge and D. L. Linton (1939)¹: "... Within an E.-W. belt only 12 miles wide all the successive stages of down-cutting, base-levelling and drift-accumulation are conveniently displayed. In neighbouring regions the same succession is either condensed by the local omission of certain terms, or else the evidence is more widely scattered. . . ." The object of the present work has been to extract all the available morphological evidence from this tract of country, and to apply it to the general problem of the development of the Thames drainage and the modern landscape.

The terraces of the Thames have, as is well known, a very extensive literature, though to an overwhelming extent the literature concerns not the terraces as morphological features, but rather the deposits of gravel and loam which build them; much attention has also been given to their included fossils and human artefacts. In short, the previous work deals mainly with the River or Valley Drifts, which may or may not be disposed in recognisable terraces. If reference is made to the first systematic account of the drift geology of our region (Whitaker, 1889) one point must strike the modern reader. Though the existence of terraces is recognised and their general significance as growth stages in the valley acknowledged, they are not separately distinguished in mapping, little or no reference is made to their elevation above the river or sea-level, and their morphological features hardly figure at all in description or illustration. It is to be recalled that the mapping which formed the basis of this account was carried out on a one-inch scale on a base-map without contours. It was not,

¹ For references, see alphabetical bibliography at end of paper.

indeed, until Howe and T. I. Pocock (1903) re-mapped the Thames valley drifts on the six-inch scale that a clear distinction of High, Middle and Low terraces was made. Later M. A. C. Hinton and A. S. Kennard (1901, 1903, 1907) proposed a scheme of four terraces as follows :—

- 1st Terrace
- 2nd (High or Upper) Terrace
- 3rd (Middle) Terrace
- 4th (Low) Terrace = Flood-plain

Later work indicated that their first terrace could not be distinguished from their second, so that the old nomenclature of High, Middle and Low retained its validity for general purposes. A certain confusion remained, however, in that Whitaker had numbered the terraces from below upward, whereas Hinton and Kennard numbered them from the top downward. Moreover, perennial ambiguity accompanied the attempt to name the terraces in terms of elevation ; the datum might be river-level, or sea-level (O.D.) and reference might be made to either the terrace surfaces or the rock-cut shelves on which they lie. As Pocock had shown, both the High and the Middle Terraces exhibited an almost negligible gradient between Staines and the sea, so that in the Lower Thames valley it was easy to speak of the " 100-ft." and " 50-ft." terraces. In the Middle Thames area (with part of which we are here concerned) the terraces showed steeper long-profiles, and it could not be assumed that they necessarily maintained parallelism with the river gradient. It was here—in the Maidenhead district—that the current system of nomenclature had its origin. Terraces were named from type localities where adequate exposures were available (Geological Survey, 1911),¹ the three main terraces being called the Boyn Hill, Taplow and Flood-plain terraces in descending order. K. S. Sandford (1924) adopted a similar method in the Oxford district. This system has persisted up to the present day, though its adequacy has been challenged.

In the Middle Thames valley, as widely elsewhere in Southern England, gravels occur at higher levels than that of the Boyn Hill Terrace and its presumed equivalents. These are distinguished in the western Middle Thames as " Plateau Gravels " by the Geological Survey, the same colour (pink) being used for these gravels as for acknowledged fluvio-glacial gravels further east. Such plateau gravels show a considerable range of height. The highest is the Pebble Gravel.² Opinion has varied on the precise age of this deposit, but all have agreed that it is " pre-glacial," or

¹ A six-inch re-survey of the London district was begun before the First Great War, and the nomenclature quoted was adopted in 1911 ; it was first applied in published work in the Windsor and Chertsey Memoir (1915), though the type localities used were both on the Beaconsfield sheet (Memoir, 1922).

² Which is, however, distinguished from the Plateau Gravel by the Geological Survey.

at very latest, "Early Glacial" (see Wooldridge, 1927). This problem in no way concerns the present work. Below the Pebble Gravel, which caps the summit plateaux, are Plateau or Fluvio-glacial gravels at various lower levels, some on isolated hilltops and others approaching the valley drifts both in disposition and elevation. It has long proved a difficult task to separate these deposits from the highest "terrace" gravels of the Thames; indeed a scrutiny of many published geological maps shows that the distinction is and can be little more than arbitrary in the absence of palaeontological evidence. Illustrative examples occur throughout the Lower Thames basin. Thus gravels classed in the "plateau" or "glacial" category at Croxley Green (Herts) have yielded Palaeolithic implements which show that they include in fact, a terrace of the Colne¹ (H. B. Woodward, 1922). Again much speculation has occurred concerning the nature and affinities of the gravels of the Wimbledon-Kingston plateau, and of Hanger Hill, Ealing, which, though higher than the Boyn Hill terrace, and technically Plateau Gravels, might well represent remnants of a higher Thames terrace. In the light of such cases, realisation has grown that the Plateau Gravels, no less than the valley gravels, appear to be disposed in terrace-like stages. This concept has figured very largely and in many variant forms in the literature of the drift-geology of the London Basin during the last half century. For our present purpose it is neither profitable nor necessary to enumerate the large number of papers based on the underlying assumption that plateau no less than river gravel can be classified both genetically and chronologically on the basis of elevation. We find this view expressed by T. McK. Hughes (1868), D. E. Salter (1896), O. A. Shrubsole (1898), H. J. O. White (1895, 1897, 1907), B. R. M. Ross (1931) and S. W. Wooldridge (1938). All these authors interpreted the record as one of a series of drift stages, each gravel flat being deemed to mark a former valley-floor level. Other interpretations have from time to time been proposed. Thus A. Irving (1890) treated the Plateau Gravels of the Bagshot country as the dissected remains of a single torrential fan, with a sloping or irregular base. H. Dewey (1915) dealing with the northern part of the same area, while admitting that the gravel platforms form three chief tiers, found gravel also at intermediate levels. He abandoned the riverine hypothesis in favour of the supposition that gravel downwash had lodged on structural rock benches over a wide range of heights. An extreme case of "non-altitudinal" correlation is afforded by the work of J. D. Solomon (1935), who correlated not only the Pebble Gravel of the London area, but also the greater part of the Plateau Gravels, with the Westleton Beds of East Anglia, on the

¹ The "Plateau Gravels" are not, of course, *ipso facto* devoid of early human implements; any such assumption would beg a very large question. But the Palaeolithic sequence of cultures in the Lower Thames terraces is now sufficiently known for us to refer such an occurrence as that at Croxley Green to its place in the terrace sequence.

basis of heavy mineral residues. He completely dismissed the question of elevation by regarding the whole of the gravels as the remnants of a sheet warped by Pleistocene movements, thus ignoring the claim of G. Barrow, H. Bury and Wooldridge that the higher level deposits of the district (Pebble Gravel and Early Pliocene marine deposits) are essentially unwarped. If these deposits were indeed warped, co-ordinated terrace sequences would necessarily be incapable of demonstration over the district as a whole. That such terrace-sequences can in fact be demonstrated has been claimed by B. R. M. Ross (1931) and S. W. Wooldridge (1938), in recent years.

There was, however, another approach to the study of the Plateau and Glacial Gravels that yielded profitable results. It had long been clear that the belt of such gravels along the Chiltern dipslope were of northerly provenance, since they contained numerous quartzite pebbles and others derived from the Bunter Beds of the Midlands. The idea that these were introduced into the London Basin by a pre-glacial ancestor of the Thames coming through Goring Gap dates back to J. Prestwich (1890) and F. W. Harmer (1907). R. L. Sherlock and A. H. Noble (1912) and later Sherlock alone (1924) studied the belt of drifts between Marlow and Watford. South of the main tract of gravels in this reach extending from Marlow to Rickmansworth, the gravels also extend down to the 200-ft. contour, and even below. Sherlock and Noble endeavoured to reconstruct the palaeogeography of the Thames valley, and explained the relation of the Plateau and Glacial gravels roughly as follows :—

- (a) The original line of the Thames ran eastward or north-eastwards towards Watford. Sherlock (1924) extended the line of the pre-glacial Thames towards Ware at the foot of the so-called Tertiary escarpment.
- (b) The onset of the Pleistocene glaciations led to the formation of a Chiltern ice-sheet which deposited the clay with flints, and, by advancing south-eastwards across the line of the river between Bourne End and Rickmansworth, blocked its course. The ponding up of the river led to its spilling over the Tertiary escarpment, with the formation of spillways on the upstream flank of the lobe at Bourne End (now the N.-S. reach of the river from there to Maidenhead) and along the line of the lower Colne on the downstream side ; at the same time the " Glacial " gravels south of Beaconsfield were deposited as a single sheet of outwash. Later Sherlock (1924) added that the blocking of the old valley beyond Rickmansworth by the deposits of the ice-lobe that advanced up the vale of St. Albans from north-east also acted as a damming agent. Sherlock

suggested that the "glacial" gravels beyond Rickmansworth were of eastern origin, meeting the Thames gravel trains near the latter town.

The most recent synthesis is due to Wooldridge (1938) who combined the altitudinal and palaeogeographical approaches to attempt a physiographic history of the Middle Thames basin. He accepted Sherlock's (1924) view that the old pre-glacial course of the river was from the Goring Gap towards Watford, Ware and beyond, but this route, he claimed, was followed only at an early stage. In succeeding epochs, he maintained that the Thames only reached the Rickmansworth region, where it was joined by another stream coming from north-east. The combined river then flowed south-east towards London. He recognised (in part following Ross, 1931) three distinct sub-stages in the development of the drainage in post-Pebble Gravel times :—

- i. The sub-stage of the *Higher Gravel Train*, when the Thames flowed north-east to Rickmansworth and Croxley Green, where it turned south-east through what are now the wind-gaps at Northwood and Hatch End. This sub-stage saw the deposition of the highest Glacial and Plateau Gravels (at levels between 350 and 400 feet in the country with which this paper is especially concerned).
- ii. The sub-stage of the *Lower Gravel Train*, when the Thames flowed rather further south from Bourne End towards Harefield, depositing a gravel train now found at about 335–290ft., in the Beaconsfield country. The river crossed the "Tertiary Escarpment" at Harefield, abandoning the Northwood and Hatch End gaps. No reason for the southward diversion was adduced.
- iii. The *Winter Hill* substage, when the river flowed still further south, roughly from Bourne End to Hillingdon, near Uxbridge, and thence towards Wimbledon Common, depositing the Glacial Gravels which lie in the Beaconsfield region at between 270 and 200ft. above sea-level. Wooldridge also correlated this sub-stage with the main Eastern Glaciation, and pictured a large outwash train and river as proceeding from the limit of the Eastern Ice near St. Albans via the modern Colne valley to join the Thames in the Uxbridge region.

One further item of debate in the history of research needs some attention. It was pointed out above that the now famous names of the low terraces of the Thames were given by the Geological Survey from type localities near Maidenhead. These names have stood the test of time, although doubts have often been expressed about the adequacy of only three terraces to include all the varied

deposits of the undoubted river-drifts. In particular the existence of a terrace intermediate between the true Taplow and the true Boyn Hill has often been claimed. Thus Ll. Treacher and H. J. O. White (1909) pointed out that at Maidenhead the gravels, later mapped as Boyn Hill Terrace, occurred on two shelves nearly 20ft. apart. J. P. T. Burchell (1934) established the existence of an Upper Taplow Terrace near West Drayton, i.e., a distinct terrace surface intermediate between the true Taplow and the true Boyn Hill surfaces. All along the Thames valley the Boyn Hill gravels as mapped by the Survey occur in a wide range of heights, suggesting that two distinct terraces may have been included. W. B. R. King and K. P. Oakley (1936) went even further. They agreed with Treacher and White that the Boyn Hill gravels rested on two distinct benches near Maidenhead and Burnham Beeches. They claimed that these two benches were both buried by one prolonged aggradation of some 100 feet ; it is not clear in their account how the lower of the present shelves was re-excavated, but Oakley (personal communication) suggested that the lower feature represents a plain of lateral erosion cutting into the 100ft. or Boyn Hill gravels. This erosion must have proceeded without deposition of drift, for the writers claimed that the artefacts derived from the lower spread of gravels (which would normally be the younger) antedate those derived from the higher spread. In addition to claiming a double structure for the Boyn Hill Terrace, however, the writers claimed the existence of another drift-train between the lower Boyn Hill and Taplow surfaces ; this train they referred to as the *Iver stage*. They tentatively correlated it with Burchell's Upper Taplow Terrace.

King's and Oakley's methods were primarily archaeological, and were based on the sequence of flint industries established in the Somme valley. Their results seem to the present writer to raise great physiographic difficulties in the Middle Thames region. The dualism of the Boyn Hill feature is, however, indisputable. This question is discussed in some detail below.

It now remains to relate the present work to the foregoing history of research in the region. In brief the reach of the river lying around Beaconsfield and Slough has been subjected to an intensive morphological survey on the six-inch to the mile scale. This area includes the type localities of the Boyn Hill and Taplow Terraces, and also includes the widest and least dissected stretch of the "Glacial" Gravels. Furthermore, it is here that the divergence of the river from its old course towards Watford took place. The region should, therefore, be critically important in deciding both the character of the drifts above the river-terraces and also the physiographic history of the Thames basin. A complete

morphological map of the region is presented (Pl. 13). The essential results can be summarised as follows :—

1. The division between Glacial, Plateau and river drifts is arbitrary and conventional. These gravels together represent the complete terrace record of the modern Thames from Pebble Gravel times onward, and any division of the associated drifts which separates the higher from the lower terrace stages is unnecessary and misleading. The descent of the Thames from the Pebble Gravel surface to the present flood-plain was marked by the formation of at least seven well-developed cut- and built-terraces, each with an associated gravel or drift train. Of these seven, two have not previously been described, three were described—by Ross and Wooldridge—and the remaining two are the Taplow and Boyn Hill Terraces.
2. The modern landscape consists largely of these seven terrace surfaces and the intervening bluffs, though subsequent stream erosion and gravitational wasting have in places destroyed the clarity of the record.
3. The evolution of the great bend of the river at Bourne End is traced in detail. It is shown that it began contemporaneously with the sudden growth of the Colne drainage and of the volume of associated debris discharged into the Thames flood-plain. The point of confluence of the two rivers is traced through the stages of downcutting. Indirect evidence is afforded supporting Wooldridge's correlation of the Eastern Glaciation with the Winter Hill Terrace.
4. Traces of a drainage system south of the present valley contemporary with one of the middle terraces of the Thames are described.
5. A cartographic technique suitable for the field mapping and interpretation of terraced and polycyclic landscapes has been devised.

In order to avoid frequent difficulties in the nomenclature of the drift deposits, the classification suggested by Wooldridge and Linton (1939) has been adopted here. They divide the drifts into three primary stages based largely upon altitude and genetical affinities :—

Stage	Height in Region under study	Deposits included
I	c. 450ft.	Pebble Gravel and Westleton Beds of East Anglia.
II	150-400ft.	The Plateau, Glacial and fluvio-glacial gravels of the Geological Survey.
III	less than 200ft.	The acknowledged Thames terrace and flood-plain gravels.

In the succeeding pages these stage numbers will be used to identify the drift deposits whenever a collective term is needed.

II. CARTOGRAPHIC METHODS EMPLOYED

The central method of the present work has been to make a complete morphological survey of the region under study. Instead of an arbitrary selection of detached pieces of evidence that seem important to the thesis, the method has been to extract all the available evidence from a limited area, and to make a morphological map of that area as complete as the average geological map. The method can be termed intensive, in contrast to the extensive, selective methods normally used in this kind of work. The region studied is comparatively small, yet even so the fieldwork took an aggregate of many months of time, spread over two or three years. It was found necessary to devise an entirely new technique of fieldwork, of mapping, and of presentation; the type of survey envisaged was not new, but the writer could find no precedent for such a survey of a polycyclic landscape of this character, and he was compelled to work out his own methods. Eventually the survey was completed on the six-inch to the mile scale over the area marked on Pl. 14, comprising eight six-inch quarter sheets, or about 50 square miles. It was extended on the 1/25,000 scale to the area covered by Pl. 13, which includes about 75 square miles. Finally, the detailed field survey suggested certain further correlations which have been presented on the considerably smaller scale (Pl. 14).

The problem of geomorphological mapping may be likened to the parallel geological case. The good geological map shows two principal items: (i) the relative age and (ii) the lithology, of the deposits. At any point on the map it is possible to derive both the age and the character of the subsoil either by direct inspection or by reference to the legend. Similarly the geomorphological map must show both the chronology and the morphological type of each facet. It must show, for example, that the ground at point A is river terrace, of the Boyn Hill stage, or that at B it is an exhumed peneplain, of Cretaceo-Eocene age and exhumed in the present erosion cycle. Figs. 31 and 32, therefore, are best understood by analogy with the geological map. Both the age and morphological type of each facet is shown.

It will be realised that this method depends on the facet concept developed by the earlier geomorphologists (notably W. M. Davis). It is implied that the whole landscape is divisible into a mosaic of small morphological units, each of which has a characteristic age and form. These facets are the relics of once larger surfaces that have been cut up by erosion. They are analogous to the outcrop of a geological stratum.

The technique of geomorphological mapping must depend on the type of terrain to be mapped. The geologist is able to employ much the same kind of mapping technique in all kinds of terrain, but the geomorphologist has to adapt his methods to the particular area in which he is working. The methods used in this present

survey should be applicable without serious modification to any other stretch of terrace country, whatever the character of the terraces. They would, however, be useless in mapping such polycyclic landscapes as the Derbyshire Peak District, where none of the facets are flat. This is at once the weakness and the strength of geomorphological survey; it is useless to attempt a uniform system of presentation for all areas, so that though local survey gain considerably in clarity and precision, yet on the other hand, it is difficult to compare one local survey with another.

The country surveyed here consists almost exclusively of terraces of the Thames or its tributaries, of the bluffs separating the terraces, and of present-cycle or very recent minor tributary erosion features. The facet-types can be defined as follows :—

- i. *The terrace surfaces*, which are gently tilted planes. The word terrace is used in this account to refer to the upper, or terminal, surface of the terrace. The drift underlying the surfaces is referred to as the drift- or gravel-train of the terrace. The shelf in solid rock underlying the deposits has not been given a generic name, and little cause will be found to refer to it.

The terraces, geometrically speaking, approximate to gently tilted planes. They have as a rule components of tilt along and across the direction followed by the river. These components can be referred to as the longitudinal slope and the transverse slope respectively. The resultant of the two slopes rarely exceeds five feet in a mile, and the slope of a terrace is generally invisible to the naked eye. For all local purposes the terraces can be looked upon as flat, level surfaces. On the maps they have been left devoid of any morphological symbol (see Pls. 13 and 14). No attempt is made on the maps to show the slope of the terraces. The limits of the terraces are shown by the bluffs separating adjacent terraces.

- ii. *The bluffs*. The steep rises which bound plains of lateral erosion such as river flood-plains are generally called "bluffs"; the term is used here to describe the rises separating the terraces. The bluffs are usually fairly steep, even though the height interval between adjacent terraces is small. They are indicated on the maps by a system of conventionalised hachures, bounded by continuous lines marking the upper and lower limits of the bluff. The device is illustrated in Fig. 30 (b). Fig. 30 (a) shows the appearance of the bluffs on the ground. AB and CD are the leading edge of terrace II and the rear edge of terrace I respectively, i.e., they are the limits of the flat surfaces. These two lines appear on the maps as the approximately

parallel pair of lines limiting the bluff (see Fig. 30 (b)). The slope of the ground between AB and CD is indicated by the series of almost parallel straight lines (conventionalised hachures) drawn directly down the slope (ignoring small irregularities) from the bluff top to the bluff base. No attempt is made to indicate the belt of maximum slope

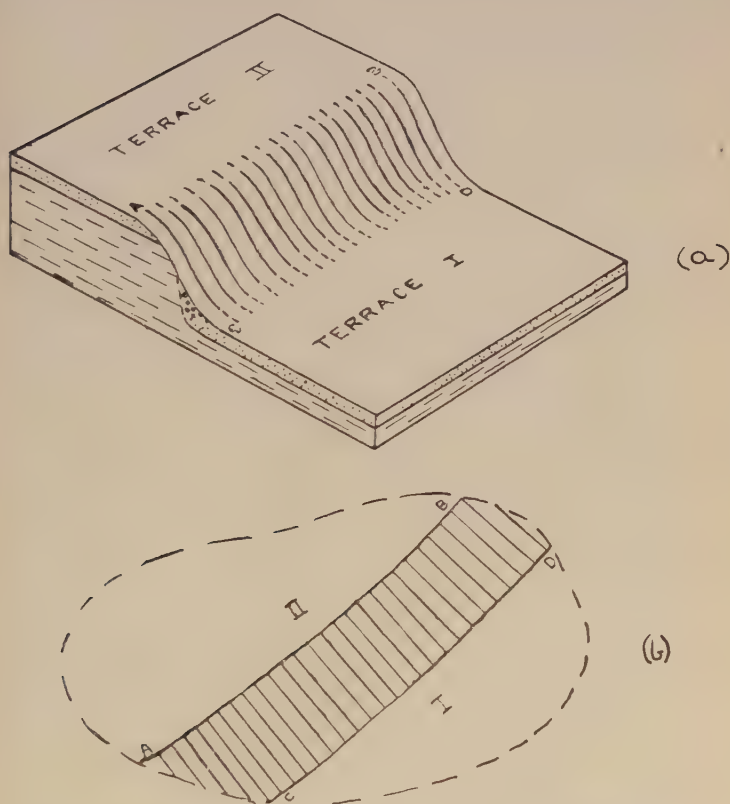


FIG. 30.—THE METHOD OF SHOWING BLUFFS ON MAPS is indicated above. (a) is a sketch of the bluff as it appears on the ground, and (b) is the device used on the corresponding map.

(which usually occurs half-way down the bluff) or to show where the curvature changes from convex upwards to concave upwards (which also usually happens midway down the bluff). The direction of slope is not shown, as it has been found that this is self-evident on the maps.

Simple and unpretentious as this convention is, it has been found to give satisfactory results in practice. A glance at Pl. 13 will show that both the terraces and the bluffs show up clearly on the maps. The bluff is obviously of the same age as the terrace at its foot, but to describe it fully one must also state the age of the upper surface into which it cuts ; thus one talks of the "Taplow-Lynch Hill bluff," or "the Winter Hill-Harefield bluff." This convention is made necessary by the fact that the terrace at the top of a bluff is quite independent of the terrace at the base. Thus the terrace at the top of the bluff contemporary with the Taplow Terrace is normally the Lynch Hill Terrace, the next in age. But in places the Taplow Terrace cuts back to the Black Park Terrace, and its bluff is then correspondingly larger.

This conventional system of showing bluffs was suggested to the writer by the sketches of W. M. Davis in his numerous papers on river terraces. It has certain obvious limitations which might be overcome by clever cartography, though this has proved beyond the writer's powers. The most obvious limitation arises out of the difficulty of indicating the height range occupied by the bluff. Since all the terraces tend to fall in height downstream at much the same rate, it follows that the height-range of the bluff between adjacent terraces varies only slowly. Thus the bluff between the Boyn Hill and Black Park Terraces is about 35-40ft. in height everywhere, though, like the terraces, its level above the sea falls steadily downstream. As a landscape feature it is hence fairly constant. The wasting of the bluff by gravitational processes varies, however, very widely from place to place ; in some places the bluff is still steep and narrow, but in others the wasting processes have reduced it to a wide, gentle rise. The technique used on the maps makes these gentle portions look much more impressive than the narrow, steep portions. It might be possible to overcome this defect by making the hachure-spacing inversely proportional to the width of the bluff.

- iii. *Recent minor tributary erosion features.* Over much of the region studied, dissection of the terraces by minor tributaries is in a juvenile stage of development. The total area of dissected ground is considerably less than that of the terraced interfluvies. Further east on the London Clay, however, recent erosion has largely removed the terraces. It was necessary to devise some convention whereby the limits of the tributary erosion features should be made clear. In Pl. 13 the device used is to enclose the valleys by a continuous line representing the valley-lip, pecked on the downslope side.

The major tributaries of the Thames have flood-plains and terraces continuous with those of the primary river, and the technique employed in their case is the same as for the Thames features. The only major tributary affecting this region is the Colne, which has a well-marked terrace-flight. The Wye is an intermediate case. It has no traceable terraces, but locally has a flood-plain. The Alder Bourne and Misbourne are minor tributaries, though here again modern flood-plains are seen locally.

The foregoing account will have made clear the essential steps in field survey. Since the local landscape consists of slopes and flats, the mappable features are breaks of slope, either valley-lips or bluff-limits. The main step in survey has therefore been to trace these breaks across country on the six-inch field sheets. They have been mapped by eye-estimate with reference to field boundaries. The actual process consists of pinpointing the break on the hedges or fences bounding the field, and then sketching its course across the field by eye. Difficulties arise in wooded country, where this kind of sketching is not very accurate. Even here, however, reasonable results can be obtained by eye.

Many of the sloping facets mapped have very indefinite boundaries. The exact position of the break of slope at the top, or at the foot of a bluff is often very hard to determine; the course adopted in deciding such cases is the conservative one of favouring the slope rather than the flat. This tends to minimise the area shown as terrace and to exaggerate the extent of the bluffs and the tributary valleys. Since so many of the results cited here depend on the evidence of the flat surfaces, however, it was felt that a scrupulous approach would pay good dividends.

No attempt has been made in most cases to support the eye-estimated lines by instrumental methods. It was found necessary in some cases to identify bluff-edges on the far side of valleys by instrumental levelling (with the Abney level) and most of the bluff-edges have at some time in the work been roughly levelled, chiefly in order to get supplementary spot-heights. These do not, however, really amount to instrumental support of the eye-work.

The next step (which in practice is usually carried out simultaneously with the mapping of breaks of slope) consists in analysing the slopes and identifying the mapped features. It soon becomes easy to distinguish in the field between bluffs and valley sides. The latter are naturally duplicated, whereas the former occur singly. There is also a characteristic difference between the features in plan; the bluff-edge usually runs fairly straight, whereas the valley-lip has a winding outline. If one can see across the valley, of course, identification is obvious, but in much-wooded

Buckinghamshire it is by no means as easy as it sounds to identify bluff and valley ; it is a knack acquired in the field.

The final and essential step in constructing the map is the analysis of the field results to determine chronology. The identification of terraces is a simple matter once the full sequence of stages is known, as the approximate level at which each should occur is then known to the surveyor before he goes into the field. This forewarned approach has its pitfalls as well as its advantages. It can be attacked on the ground that one is very apt to find only what one wants to find in the landscape. In this case the evidence is generally too clear to allow such self-deception. The simple but hard and fast field technique also rules out special pleading. The principal valid objection is that the surveyor may be thrown into confusion by the presence of local facets not fitting into the general picture. Such country occurs south of Gerrards Cross, near Hedsor, and again north of Burnham. The surveyor has to enter the field with a judicious blend of foreknowledge and wary open-mindedness. Much the same attitude is called for in the geological surveyor. In order to clarify the meaning of the maps, longitudinal- and cross-sections have been drawn. The cross-sections (Sections I-VII, Pls. 15/16) are simple scale-sections (vertical scale 25 times horizontal) across the terraces, showing the "stair-case" effect. Sections I-V run along north-south gridlines, which can easily be placed on the grid-net on Pl. 13. The enormous vertical exaggeration was made essential by the detailed character of the cross-sections. The principal facets are emphasised by extra-thick parts of the sections.

The longitudinal profiles (Figs. 31-32, Plate 17, VIII-XIV) present many problems of interpretation, and are of a lower degree of validity. Even with a modern flood-plain, the exact meaning of a long-profile is hard to estimate. Should the profile be taken along the water surface, meanders notwithstanding, or should it be taken along the median line of the flood-plain? Both courses present advantages, and they are mutually related through the meander-coefficient of the river. This coefficient, however, varies both in time and in space, so that physiographically it is the profile of the flood-plain surface rather than that of the river that matters. In the case of terrace-relics it is even harder to produce satisfactory long-profiles, and Figs. 31-32 must be regarded as tentative. In most cases less than half the original surface of the flood-plain now represented by the terrace has survived. It is hence impossible to draw any median line along a terrace. A median along the surviving terrace relic has obviously little value, since its position will depend on the extent to which later terraces have cut the terrace in question away. By the same token the leading edge of a terrace relic has a quite arbitrary course, and a section along it is of no value. The rear edge of a terrace is a far sounder line to take, but here there are

difficulties due to the accumulation of waste from the bluff behind, which locally builds the terrace up above its original level. The recourse adopted in Figs. 31–32 is the purely arbitrary one of drawing transversals across the terrace (at right angles to its general run) every quarter-mile and plotting the highest and lowest heights of the surface on each transversal. A smoothed curve is then drawn through the points so obtained.

III. THE FIELD EVIDENCE IN THE COUNTRY ROUND SLOUGH AND BEACONSFIELD

In this section the results of the field surveys will be discussed in detail. These results are summarised cartographically in Pls. 13 and 14 and by scale sections in Pls. 15–16. The analysis has shown that the drift-covered, plateau-like block of country between the Cookham-Bray reach of the Thames and the Colne consists of a flight or “staircase” of terraces, all of them plainly linked in origin with the Thames or Colne drainage. Three of these terraces, the Flood-plain, Taplow and Boyn Hill, are widely known, and are well developed in the area. It is now clear, however, that the higher ground above these terraces is also terraced, and it is evident that higher and older stages of the river drifts underlie them. It is also shown that the Boyn Hill feature is in reality dual, an extra terrace appearing between the true Boyn Hill and the Taplow.

The terrace succession can be summarised as follows, starting from the highest levels and working down to the flood-plain:—

Terrace.	Height on meridian of Slough Station.	Remarks.
i. <i>Higher Gravel Train</i> (Wooldridge, 1938)	350–375ft.	Terrace structure largely destroyed.
ii. <i>Harefield Terrace</i> (Hare)	305–315ft.	Lower Gravel Train of Wooldridge for most part.
iii. <i>Winter Hill Terrace</i> (Wooldridge and Ross, 1932, 1938)	255–260ft.	Colne drainage initiated, also southward movement of Thames.
iv. <i>Black Park Terrace</i> (Hare)	c. 210ft.	Southward shift of river continued.
v. <i>Boyn Hill Terrace</i> (Geological Survey, 1911)	c. 175ft.	Not including all Boyn Hill as mapped by Geological Survey.
vi. <i>Lynch Hill Terrace</i> (Hare)	c. 130ft.	Probably Iver Stage of King and Oakley (1936) and Upper Taplow Terrace of Burchell (1934)
vii. <i>Taplow Terrace</i> (Geological Survey, 1911)	c. 100ft.	Colne terrace also well developed.
viii. <i>The Flood-plain</i>	65–70ft.	—

Much the greater part of the terraced landscape is divisible into these major facets. There are minor facets visible in places a little above or below the main levels.

(i) The Higher Gravel Train

In his account of the higher drifts of Thames origin, Wooldridge divided the highest drifts into a "Higher" and a "Lower" Gravel Train. He deliberately avoided the term "terrace," as the surface of these gravel trains was irregular and devoid, as he thought, of any widely recognisable terrace features. In the region now being discussed, both trains enter near Bourne End and run east or north-east past Beaconsfield. The wide gravel plateau round that town he has found to be wholly referable to one or other of the stages.

The drifts of the Higher Gravel Train occur in the Beaconsfield area at levels varying from 340 to 380ft. above O.D. (260–300ft. above the river). The present survey confirms that no continuous terrace features can be seen in them. In several places there are local flat areas within the height range referred to (as at Beaconsfield Church), but they cannot be linked together downstream. The whole surface of the Higher Gravel Train in this area is deeply dissected by tributaries of the Wye, Misbourne and Alder Bourne, many of which are now dry. The undissected surface has also been attacked by solution, as most of the train is spread over high and dry Chalk. Nothing systematic emerges from a morphological survey of the surface.

The bluff bounding the train on the north is clear-cut and still of vigorous relief, being cut in Chalk. Its position is indicated on Pl. 14. Its base is at about 380ft. in the west, but it seems to fall eastwards to about 360ft. near Chalfont St. Giles. The bluff is as deeply dissected as the train, and is difficult to find in a first visit. A walk north along any of the interfluves near Seer Green makes the feature obvious, as it can then be seen that the abrupt break of slope has nothing to do with recent dissection. One further item of note within the Higher Gravel Train country is the east-west valley north of Beaconsfield Old Town used by the main line of the Great Western Railway. The cross-roads in the Old Town near Saracens Head Hotel are at 374ft., and lie on a detached part of the Higher Gravel Train surface. The ground falls northwards towards the station, which lies in a deep cutting at the floor of the valley referred to. The main valley floor is at about 345ft., is flat and is bounded by more or less clearly marked bluffs. At first the writer assumed that this valley was nothing but the joint head of the two dry valleys that encroach upon it from east and west. The form, however, suggested rather that it was a relic of an old aggraded flood-plain. A temporary section near Beaconsfield station in 1939 showed at least 20ft. of bedded fine gravel with intervening loams and a six-inch clay band. The drift contained Bunter quartzite pebbles. No certain answer can be given as regards the origin of this trench, but the writer is inclined to regard it as the abandoned

course of a tributary contemporary with the Lower Gravel Train stage, coming from the north-east (see below).

(ii) The Lower Gravel Train : The Harefield Terrace

The lower of Wooldridge's two high level drift trains enters the region on the crest of the steep cliffs behind Hedsor and Wooburn. It runs a little north of east towards Harefield. Wooldridge (1938) considers that it then ran eastward south of the high ground of Batchworth Heath and Oxhey Wood, but all trace of it has been lost.

Like the Higher Gravel Train, much of its surface has been cut away or disturbed by dissection and solution. Many of the gravels included by Wooldridge in this Stage are certainly below their original level, but others show by the undisturbed character of their bedding that they are still in position. Morphologically the train includes at least one clear-cut terrace, whose smooth, gently tilted surface closely resembles the flood-plain of today. For this feature, the highest surviving recognisable terrace of the Thames, the name *Harefield Terrace* is suggested.

The *Harefield Terrace* is seen on Pl. 13 near Hedsor and Bourne End. Its upper surface is at about 330ft. on the crest of the Wye valley and is remarkably flat. The surface of the terrace is often waterlogged in winter, probably due to loamy or clay bands in the underlying gravel. Innumerable rivulets run down off the terrace top on to the Chalk at each valley side, where they sink into deep swallets. The terrace runs eastwards towards Collum Green, falling at about 5ft. a mile. There is also a gentle north-south slope, the terrace being lowest at the southern lip. At Hedsor the lowest ground that can be regarded as undisturbed is at about 320ft. and the highest at about 330ft. At Collum Green the lowest part of the original surface is at 305ft., but the higher part is cut away by recent erosion. The characteristic form of the terrace is hence that of a tilted plane, the component downstream being smaller than the transverse slope from terrace bluff to river ; this will be shown to be typical of the modern flood-plain and of most of the other terraces.

The bluff separating the terrace from the higher ground to the north is not clearly marked. North of Wooburn Common there is a steady but very gentle gravel-strewn rise to about 340ft. near Holtspur, beyond which the ground is cut away by recent erosion. South of Beaconsfield, however, there is a pronounced bluff on the main Slough road, which is a little over-emphasised by a modern tributary dry valley which dissects the Harefield Terrace here.

East of Collum Green the Harefield Terrace is badly dissected ; it occurs on the crests of some of the interfluvies around Hedgerley, but is largely cut away in Bulstrode Park. At Gerrards Cross there is a fairly wide flat surface at about 280ft., which is definitely

too low to be part of this terrace. On the Misbourne-Colne interfluvium there are traces of a level feature at 290–300ft., which is right on the extrapolated profile. At Harefield, on the far side of the Colne valley, the terrace is fairly flat and clear cut. The northern bluff is at about 290ft., and the lowest ground is at about 280ft. This gives an average slope eastwards of 3–4ft. a mile, from Collum Green, which is less than the slope west of Collum Green.

The stretch of flat, gravel-strewn ground at Gerrards Cross about 15ft. below the lowest part of the Harefield Terrace has a counterpart at Cliveden, where there is a small, narrow shelf at about 290ft. The writer regards these as relics of a minor stage of erosion at the end of Harefield Terrace times; they are probably the path taken by the meander-belt during an early phase of the down-cutting preceding the Winter Hill stage. They are marked as substage H_1 on the maps.

A long-profile of the Harefield Terrace is given in Pl. 17, section VIII. The terrace also shows up well on the north-south sections (sections I–III).

Although the evidence of the ground is too scanty to allow certainty, certain features of the surface north and west of Beaconsfield suggest that the Thames was joined here by a tributary with an extensive flood-plain. The gravel-strewn surface stretching northwards from Hedsor (Nobleman's Corner) to the dry valley north of Holtspur has a gentle, but unmistakable north-south slope from about 315ft. at Hedsor to a maximum of just under 340ft., or about 5ft. a mile. The floor of the trench north of Beaconsfield is at about 345ft., and it can be tentatively linked with the Holtspur surface. The slope of the Harefield Terrace near Hedsor may be the normal transverse slope of the Thames flood-plain, but it is inconceivable that the slope could extend over a range of 25ft. It is also difficult to see how the flat between Flackwell Heath and Beaconsfield (Old Town) could have been cut by a Thames meander (see Pl. 14); deep embayments of this sort do not occur on the modern flood-plain. The Holtspur feature and its northern detached relics near Forty Green are hence tentatively regarded as the flood-plain of a Thames tributary which may have come from the north-east through the gap by Beaconsfield Station; it is possible also that another tributary came down the line of the modern Wye. The Beaconsfield stream may possibly have been that which deposited the Brantford Grange Bunter-bearing drift (see Sherlock and Noble, 1922), and this correlation is tentatively made on Pl. 14.

(iii) The Winter Hill Terrace

The sharp spur of high ground in the great bend of the modern Thames at Bourne End is truncated at its nose by a narrow bench cut in Chalk. The bench is at about 250ft., and it was regarded by

Wooldridge and Ross (1932, 1938) as a representative of a major terrace stage of the Thames. They named it the Winter Hill Terrace, Winter Hill being the name of the tiny hamlet near by. There is a thin cover of bedded gravels (exposed in 1939 near Hillgrove Farm), but much of the surface is almost bare Chalk, as a now dry tributary valley has dissected the bench. There is a wide enough patch of flat, gravel-strewn surface around this valley to permit the mapping of a terrace-facet at about 250ft., but the writer is not satisfied that the surface is original.

East of the river, however, the terrace widens out and becomes perhaps the best-developed and widespread of all the terraces. A small patch of the terrace survives south of the Feathers Inn, Burnham Beeches and Dorney Wood, where it widens to about $\frac{1}{2}$ -mile. Here the surface is very flat at about 260ft. The surface is often waterlogged, apparently through pan formation, since the well-bedded and coarse gravels underlying it are well exposed and contain no clay.

A deep tributary valley breaks right across the terrace in Burnham Beeches. East of this valley the terrace is resumed on East Burnham Common, and it forms the wide flat on which the modern settlement of Farnham Common is built. The terrace here has two minor facets separated by a distinct bluff or levee, in one place 10ft. high. The northern half of the terrace around Egypt village and the Royal Oak Inn is at 260ft., and is quite flat. The minor bluff cuts the Slough-Beaconsfield road by Templewood Lane, although it is hard to dissociate it from the side of the tributary valley cutting across here. The lower sub-facet occurs around the main village centre of Farnham Common and is at almost exactly 250ft.

Another tributary valley cuts across in Brockhurst Wood, and yet another north of Stoke Court. On the interfluvium between them it is not possible to distinguish between the two sub-facets; on the whole the interfluvium slopes gently southwards from about 257ft. in the north to 250ft. near Rickman's Hill.

By far the best relic of the terrace, however, is that which forms the wide expanse of Stoke Common. This plain is at 257ft., and accurate levelling is needed to detect any slope at all. The soil is too thin and ill-drained (again probably through pan formation) to allow cultivation, and the core of the relic is given up to heath and podsolised soils. There is no more convincing terrace in the London Basin than this high, infertile plateau.

East of Stoke Common analysis is complicated by the deep erosion of the Alder Bourne and its tributaries, and by the fact that the terrace is here cut in London Clay. The spur of high ground running from Fulmer Botanic Gardens to Heathfield Plantation and the Clump has a bevelled gravel-covered crest, mapped as a continuation of the Winter Hill Terrace, but it slopes steeply

eastwards at Fulmer Common, beyond which it is at only 237–240ft. North of the Alder Bourne, however, there is a wide relic of the terrace round St. Huberts and Tatling End. This ground is at 255–265ft. in the west, but a minor bluff crosses it, and at Tatling End the ground is at about 248ft. Here again there are two minor sub-facets. Two tiny relics of the lower sub-facet occur N.W. of Rush Green, at just under 240ft., but they show signs of cambering.

This traverse down the terrace has now brought the story to the Colne and Misbourne. East of the Colne the terrace has been completely removed by recent erosion of the London Clay. It is possible, however, to trace relics of the Winter Hill Terrace up the modern Colne valley. The ground has not been mapped on the six-inch scale, so that the following account is necessarily of a lower order of accuracy.

The first of these Colne valley relics occurs at Oakend Wood, east of Gerrards Cross, and there is another, badly cambered, on Denham Golf Course. Neither of these features is as flat as Stoke Common, but both are plainly terrace relics. The original surface of these features is at 260–265ft.

There is then no further trace of the terrace until just north of Harefield. The spur of high ground in the bend of the Colne near Mill End has a conspicuous shelf cut into it. The spur is dissected by an active stream, and the terrace relic is divided into two ; the larger element is seen at c. 270ft. round Weybeards and Hillend, and the smaller at about the same level on the flank of Woodcock Hill.

Although it lies outside the area under detailed study here, it is worth mentioning that the wide and very flat gravel plateau north of Croxley Green at about 275–280ft. falls into line with the terrace profile, and it is possible that some part of it is referable to the Winter Hill Terrace.

The Winter Hill Terrace has been described in detail here because it is the critical stage in the evolution of the valley in this region. Questions of correlation are left to a later section, but it must have been clear from the above account that the Terrace has features which differentiate it from those above and below. These can be summarised as follows :—(1) The great bend of the Thames near Bourne End was initiated at this stage. The Harefield Terrace shows a slight sinuosity hereabouts, but the Winter Hill Terrace makes a sharp S bend ; (2) The eastward slope of the terrace is very small ; in fact it hardly exists. At Cliveden the higher of the two minor sub-facets is at 255–260ft. ; at Stoke Common, five miles east, the unmistakably original surface is at 257ft. There is then an abrupt fall eastwards, but this ground is obviously not the same surface. Going north up the Colne valley the terrace *rises* from about 260ft. at St. Huberts, Gerrards Cross, to 270ft. at Mill End, a distance of about six miles. This gives a slope of $1\frac{1}{2}$ ft.

a mile from north to south. These figures make it plain that we are, in fact, dealing with the junction of two terraces, the Winter Hill Terraces of the Thames (Bourne End-Stoke Common) and of a proto-Colne (Croxley Green-St. Huberts). The two terraces converge near Stoke Common, and the wide gravel plateau around Stoke Common must represent the fusion of the two associated gravel trains.

The contrast with Harefield Terrace times is remarkable. The Thames then ran east-north-east from Bourne End to Harefield, whereas in Winter Hill Terrace times it must have run from Bourne End to Stoke Common, having by some agency been compelled to shift southward some four miles. Sherlock (1924) suggested years ago that it was the outwash of the Eastern Glaciation that diverted the Thames southward. The inference here is inescapable that the shift was caused by the piling up of aggradational material into the Thames flood-plain by a new and vigorous tributary from the north, the proto-Colne, which Wooldridge (1938) has regarded as being the outwash-stream from a lobe of the Eastern ice. If drift is added to a flood-plain in this manner beyond the capacity of the river to remove it, then the river must either aggrade its upstream flood-plain so that it can overtop the growing delta, or else shift laterally. The morphological evidence is that the Thames did both. The lack of eastward slope between Bourne End and Stoke Common suggests aggradation, and the southward shift is sufficiently obvious.

The dual nature of the original surface of the terrace has been stressed above. In many places two distinct sub-facets are visible, separated by a tiny but distinct bluff of about ten feet. It is suggested that the lower sub-facet is a trench dug out by the Thames meander belt in the Winter Hill gravels at the close of the period, presumably when the outpourings of the proto-Colne had diminished.

In the Winter Hill Terrace stage we therefore have plain evidence of the beginnings of the Colne drainage as we know it today, and of the great southward bend of the Thames near Bourne End. This southward shift has to some extent been aided by unclinal shifting down the sub-Eocene plane and also along the bedding of the Chalk, but for the origin of the bend we have to look to the sudden beginning or increase in magnitude of the Colne drainage.

The mutual relations of the Harefield and Winter Hill Terraces are of interest. In the west the surfaces are 60ft. apart, and are often separated by very steep Chalk bluffs. The Harefield Terrace slopes eastwards quite steeply right through to Harefield, but the Winter Hill feature is almost level as far as Stoke Common, and thereafter slopes upwards towards the north. At Harefield the two surfaces are only 20-25ft. apart, and the bluff between them is quite small, though still traceable.

The bluff is first seen in the west at Cliveden, on the Burnham-Hedsor road. There is a sharp rise of 40ft. cut in Chalk. The upper surface here is not the Harefield Terrace, but the minor, local surface referred to on p. 310. A further bluff of 17ft. separates this local sub-facet from the Harefield Terrace, so that in all there is a 57ft. difference between the two surfaces. Further east the bluff has largely been removed by later erosion, but it is well seen at Farnham Common, where it is a quite sharp-cut 36ft. drop. Near Gerrards Cross it is again interfered with by the intrusion of a local intermediate sub-facet, but it is traceable, though small, near Chalfont Lodge on the spur between the Misbourne and the Colne. Here it is to be remembered that the terrace is that of the proto-Colne, which is trenching across the old Thames flood-plain of the Harefield Terrace. North of Harefield the Winter Hill Terrace is actually *north* of the Harefield Terrace, a north-facing bluff of about 25ft. separating them near Hillend. This bluff is complicated by the presence below it of two recent minor valleys which make the bluff look bigger than it actually is. Once again it has to be stressed that it is the Colne Winter Hill Terrace that lies north of the Thames Harefield Terrace. The Thames Winter Hill Terrace east of Stoke Common presumably ran south-eastwards towards London, but all trace of it has vanished.

(iv) The Black Park Terrace

The top of the steep Chalk cliff along the east bank of the Thames north of Boulters Lock is quite flat at about 210–220ft. A fairly steep bluff of about 40–45ft. separates this flat from the Winter Hill Terrace south of Cliveden. Wooldridge (1938) included this ground within the Winter Hill Terrace, acknowledging, however, that the latter was certainly composite. There is no doubt that this lower facet constitutes a separate and well recognisable terrace. Although cut away in places by the wide-swinging Boyn Hill Terrace, it has wide relics at Taplow, south of Littleworth Common, in Black Park and at Iver Heath. What is probably a relic of the Colne's Black Park Terrace (the name suggested here for this facet) forms the high ground of Uxbridge Common. Hillingdon lies on what is probably a cambered and degraded relic of the Black Park Terrace of the Thames, close to the junction of the two rivers.

There is no trace of the terrace on the west-bank of the river near Cookham, but a large relic occurs north of Taplow. Forming the crest of the cliff overlooking the Thames the terrace here is a mile and a half wide. Its level surface is lowest (about 211–212ft.) in the middle of this extent. At the foot of the bluff separating it from the Winter Hill Terrace it is about 214ft. The extreme southern point of the terrace, however, is at almost 220ft. This drift-covered flat is a little disturbed by large solution features, especially near the road-junction near its middle, and this slight transverse slope may not be original.

The terrace narrows considerably to the east because of the northward swing of the Boyn Hill Terrace. The Black Park Terrace itself swings northwards, and in the Dropmore Estate and south of Littleworth Common has actually cut the Winter Hill Terrace away. A steep bluff of almost 100ft. separates it from the Harefield Terrace.

The Black Park Terrace is itself cut away from Burnham Beeches to Black Park, but there it suddenly reappears as a wide and very flat surface at just over 200ft. This feature continues as far as Iver Heath, where the 200ft. contour winds across it. It is then cut away by the Colne valley. The terrace has fallen 20ft. in seven miles, an average of about 3ft. per mile. We lose it at about 197ft. near Iver Heath. Three miles further east it should lie at about 188ft.,¹ which is exactly the height of the highest ground of the much dissected and cambered Hillingdon plateau. This can safely be correlated with the Black Park Terrace. It is quite likely that the flat-crested ridge of Uxbridge Common (200–210ft., apparently rising northward) represents a relic of the Colne valley equivalent of the Black Park Terrace, though there is no other trace of it below Rickmansworth, except for a thin and rather doubtful patch on the west bank north of Denham Film Studios.

Like all the other terraces, the Black Park Terrace is amply covered by drift, though it is badly exposed. Although the character of the drifts is outside the scope of the present work, it is perhaps worth noting that the Black Park drifts differ very much from those of the Winter Hill Terrace above and the Boyn Hill Terrace below. They contain much ill-sorted, pebbly loam, with occasional bedded gravels. The basal beds of the drift-cover are exposed in Black Park and are mapped by the Geological Survey as an isolated patch of "Pebbly Clay and Sand," which is a fair description of the whole terrace's drift.

The bluff bounding the terrace on the north is well developed north of Taplow (40–45ft. to the Winter Hill) on the Maidenhead-Beaconsfield road, and still better south of Littleworth Common (about 100ft. to the Harefield). It is also well seen (50ft. to the Winter Hill) along the south-western border of Burnham Beeches. It is gradual and much spread out by soil-creep near Pinewood Studios.

The Black Park Terrace continues the southward swing of the river initiated in Winter Hill Times. The Colne-Thames junction appears to have been somewhere near Cowley, south of Uxbridge, and the Colne has taken up the course which it has followed ever since. Unlike the Winter Hill Terrace, however, the Black Park Terrace has a steady eastward slope, and shows no sign of the ponding and pronounced aggradation characteristic

¹ Assuming linear extrapolation, which is safe over such short distances.

of the Winter Hill west of Stoke Common. We may cautiously deduce that the flow of debris from the Colne was reduced to some extent during this stage, though still appreciable.

(v) The Boyn Hill Terrace

With the Boyn Hill Terrace, we come to the terraces and drift trains following the modern river so closely that for many years they have been accepted as terraces of the river. To some extent, therefore, their form, shape and behaviour offer a yardstick by which to measure the higher level terraces. The following account is therefore very detailed.

The Boyn Hill and Taplow Terraces are very well developed in this region, which includes the type localities. The gravel trains associated with them are mapped by the Geological Survey, but in places it will be necessary to differ from their interpretation. An example occurs along the dry chalk valley running north-south from Burnham Beeches to Hay Mill Pond, which coincides with the sheet line separating the Burnham from the Farnham Royal six-inch field sheets. At Cants Hill the valley is quite narrow, and the flat ground on either side of it is at precisely the same level, about 175 ft. On both valley flanks the base of the gravels underlying the flat can be traced at about the same level. As far as can be seen the gravels are identical. Yet the eastern flank is mapped as Boyn Hill and the western flank as fluvio-glacial gravels. Morphologically it is quite clear that the surface on both sides of the valley is the same feature. Another point of difference is that morphologically it is certain that there is another terrace between the Boyn Hill and the Taplow. Both features are normally mapped as "Boyn Hill" by the Survey. The term "Boyn Hill" is confined in this paper to the higher surface, which is that which forms the surface of Boyn Hill itself.

The westernmost relics are at Boyn Hill and Furze Platt, west and north-west of Maidenhead respectively. These have an extensive flat surface at 165–170ft. Both of them are cut in Chalk, and their terminal bluffs are small incisions into the sub-Eocene plane. Both of them are well-exposed, and they have served as good type localities for both the terrace and for the associated artefacts. They are clearly distinct from the patches of Boyn Hill gravels mapped by the Survey north of Cookham Rise, which are below 150ft. O.D.

On the far side of the river the terrace is picked up at Hitcham and at Burnham. Again we exclude the Boyn Hill gravels mapped by the Survey at below 150ft. south of Burnham. The tiny triangle of Boyn Hill Terrace west of Hitcham is probably not the original surface, as its drift cover has been largely removed. The bluff separating it from the Black Park Terrace is a bold Chalk feature

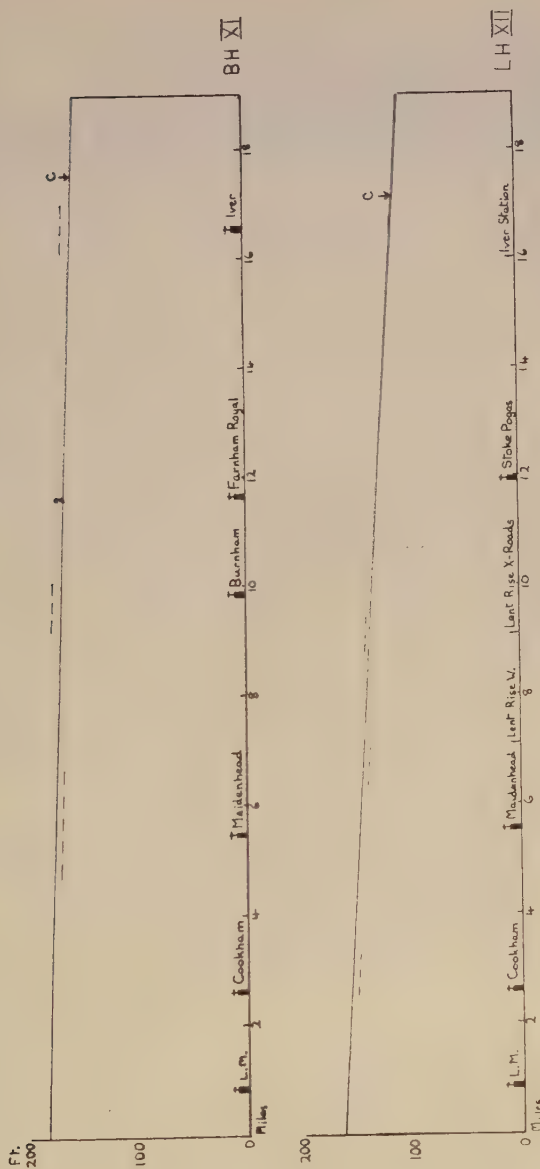


FIG. 31.—SECTIONS XI-XII.

Long-profiles of the Boyn Hill (XI) and Lynch Hill Terraces of the Thames. These follow the conventions of Pl. 17. Both features have marked southward transverse slope, and the dotted lines indicate the north-bank (above profile) and south-bank (below profile) extreme levels.

some 38ft. high on the Hitcham-Taplow road. North of Burnham, however, the terrace is wide, flat and little disturbed except by the Hay Mill dry valley. The surface level is from 175–180ft. The great northward swing of the river which took the northern boundary bluff more than a mile north of Burnham was the last apparent effort of the river to get back to its old course. It is worth noting here that there is a considerable contrast between the deposits within the loop and those along the southern edge of the terrace ; at Rose Hill, in Poyle brickpits, the deposits are loamy, with considerable brick-earth layers, and only occasional coarse, Bunter-bearing gravels. Round Burnham, on the other hand, the drift is a coarse, well-bedded gravel with some very large boulders. It looks as if the embayment, once cut by the meander-belt during the pre-Boyn Hill downcutting, was very much of a back-water during the subsequent aggradation ; it probably was a low-lying swampy area of alluvium-formation to the north of the main gravel train.

The terrace is well seen south of Burnham Beeches, and again north of Farnham Royal, where it is at 170–175ft. It is present in patches further east at Stoke Poges and at Rowley Wood, north of Wexham, but much of this stretch has been cut away by a peculiar facet discussed below under the name of “Stoke Park Cut,” It is cut away again in Langley Park, but remains as a small relic at Bangors Park, north of Iver. It is here at about 167ft., although a considerable southward slope suggests that the feature may be entirely covered by solifluction trail from the bluff to the north. The country north of Iver is very difficult to analyse, as all the bluffs lengthen and flatten out to the east, roughly, of the Wexham to Fulmer road. The bluffs in this area are all cut in London Clay, and there is little doubt that this slippery base was responsible for the large scale smoothing out of the bluffs.

It is very difficult to estimate the longitudinal slope of the Boyn Hill Terrace. To begin with, the terrace has a considerable transverse slope. At Maidenhead the highest ground is at about 170ft., whereas at Burnham, on the opposite side of the flood-plain and a mile downstream, there is ground at 180ft. ; this indicates a transverse slope of some 10ft. Since there is no means of telling whether this is true all the way along the feature, it is hard to draw a representative long-profile. The difficulty is made all the greater by the strong suspicion that all the ground between the Lynch Hill and the Black Park terraces north of Iver is covered by a spread of trail. One can do no more than suggest that the Boyn Hill Terrace has a relatively gentle eastward slope ; for if one accepts the values given above for Burnham and Bangors Park as being representative of the northern side of the flood-plain, the longitudinal slope is only about 2ft. a mile.

The Stoke Park Cut is a curious erosion feature which cuts into

the Boyn Hill Terrace east of Farnham Royal. The cut is an inclined plane sloping eastwards at about 7ft. a mile. It is separated from the Boyn Hill by a small bluff which naturally grows bigger eastward, since the cut slopes eastward more steeply than the terrace. Near Black Park it is necessary to map this minor bluff as a true terrace bluff. The outline of the bluff in plan is arcuate, and concave towards south. Its course from Farnham Royal to Black Park is roughly the arc of a circle. The surface of the cut is very flat, and there is little transverse slope. There is gravel beneath its western end, but east of Stoke Poges Golf Course the surface is mainly London Clay with only a few patches of thin gravel. It is suggested that this cut, unique in the region, is the strip of Boyn Hill Terrace pared off by the downstream sweep of a meander during the early stage of the phase of downcutting that ended the Boyn Hill stage.

(vi) The Lynch Hill Terrace

Morphologically it is quite clear that a separate terrace exists between the Boyn Hill (as defined here) and the Taplow Terraces. This terrace is called here the *Lynch Hill Terrace*, from the locality east of Burnham, where it is best seen. Evidence will be brought forward later that the Lynch Hill surface is indistinguishable from the surface overlying the gravels at Richings Park classified by King and Oakley (1936) as Iver Stage deposits. If this correlation should be established, the term Iver Terrace would have preference.¹ The Lynch Hill surface is also probably equivalent to Burchell's (1934) Upper Taplow Terrace near West Drayton. These correlations are not, however, definitely established, and seem to raise difficulties archaeologically. For the moment it has been thought advisable to adopt the neutral term Lynch Hill.

The Lynch Hill Terrace is first picked up on the west bank of the river west of Cookham. It forms a marked shelf on the steep bluff separating the flood-plain from the Winter Hill type locality. The level is almost 150ft., and the surface is gravel-covered. The terrace is again present south-west of Cookham Rise, where it forms a shelf in the steep slope, this time between the Taplow Terrace and Cookham Mount. Further south it has been almost cut away by the swing back of the Taplow Terrace against the Boyn Hill. A tiny fragment remains at Furze Platt east of Cannon Court Farm, and it is here that the lower Furze Platt pit occurs. On the far side of the river there are traces of a bench at just below 150ft. in the Chalk cliff south of Taplow, but the terrace is not well developed until Lent Rise is reached. Here and all along the southern flank of Burnham village there is a continuous shelf falling eastwards from about 142ft. at Lent Rise to about 137ft. near the Haymill valley. Across the valley the terrace broadens

¹ Though the village of Iver is built on the bluff *above* the terrace.

out into a beautifully flat relic about 900 yards wide. Lynch Hill farm at its southern edge has been adopted as the type locality. The surface here is at about 135ft. Continuing eastwards one crosses the London Clay boundary, and immediately the terrace narrows because of the spread of its bounding bluffs. It is still recognisable on the Slough-Beaconsfield road (though not from it, because of the graded road surface), but it is better visible in a wide relic around Stoke Green, where its surface is at about 128ft. It is again traceable at George Green, but in Langley Park the Taplow Terrace and the Black Park Terrace are separated by an irregular and partly drift-free slope without any conspicuous flats. The same is true of the area round Shreding Green. South of Iver at Richings Park Housing Estate, however, there is a broad terrace feature at about 118ft. In detail this ground slopes gently southwards from about 122ft. at the rear to 114ft. overlooking the Taplow feature. At George Green the undoubted Lynch Hill surface is at about 125ft., having fallen 25ft. in the $9\frac{1}{2}$ miles from Cookham, a slope of about $2\frac{1}{2}$ -3ft. a mile. Linear extrapolation eastwards from George Green at this gradient gives an estimated level of 117ft. at Richings Park Housing Estate, which is in exact accord with observation. There is little doubt that this terrace feature is part of the Lynch Hill surface.

Although it is then outside the area under detailed discussion here, it is of interest to note that the Lynch Hill Terrace is easily picked up on the east bank of the Colne just south of the G.W. Railway around Starvhall Farm, and is then traceable eastwards with hardly a break to Norwood (Southall), where it is at about 100ft. The Great Western Railway main line follows its magnificently flat and gently eastward sloping surface throughout.

The bluff at the rear of the Lynch Hill Terrace is very steep at Cookham, where it is cut in Chalk, but it is more often badly degraded north of Slough. It is well seen at Stoke Green on the main Slough-Gerrards Cross road (A.332) and again north of George Green, but the bluff north of the Richings Park mass is no more than a gentle rise. The rear edge of the terrace is hence hard to map. Extensive solifluction gravels cover its upper surface (Brown, 1896) at Iver, showing the probable fate of the bluff. The Lynch Hill Terrace is recognisable in the Colne valley near Denham. Denham Village is built on an extensive, drift-strewn flat at about 130-135ft., which is probably referable to the Lynch Hill stage. The writer first identified this facet as of Taplow Terrace age and it is so marked in Pl. 13. It is probable, however, that the Taplow Terrace and the flood-plain of the Colne are one and the same thing in this locality, as the river runs over a marked knickpoint here, which probably represents the limit of headward penetration of the flood-plain stage in the Colne valley.

(vii) The Taplow Terrace

The Taplow Terrace, the youngest and least dissected of the Thames terraces, covers wide areas in this region. There are some relics of the feature along the west bank of the Thames from Cookham to Bray, but the main mass extends eastwards without a break from the type locality at Taplow (north-west of the railway station) as far as the Colne valley. Slough is built almost entirely on this terrace.

A narrow, but almost continuous, strip of Taplow Terrace runs along the western side of the flood-plain from Cookham Rise to Maidenhead, where it is cut away by the wing of the flood-plain against the Boyn Hill. A further patch, almost entirely cut away by gravel workings, occurs south of Bray. The ground falls from about 105ft. at Cookham Rise to 95-100ft. at Bray (as far as can be judged). Thereafter the feature is largely confined to the north bank. It is first picked up north of the Dumb Bell Hotel south of Taplow, where it forms a narrow but flat shelf, which widens rapidly eastwards. The level here is at about 100ft., but this may be raised considerably by wash. Apart from occasional transverse tributary valleys the feature is then unbroken as far as Richings Park, falling fairly regularly eastwards. At Slough it is at about 100ft., the 100ft. contour winding erratically across it in the town. It forms a wide shelf around Langley, where it is at from 95-100ft. Further east it is cut away by the Colne and its tributaries. Beyond the Colne it is traceable without a break into Middlesex, falling to about 80ft. at Cranford. This gives a slope of some 2½-3ft. a mile.

As in the case of the Boyn Hill, the terrace has a considerable transverse slope. The relics on the west bank about Maidenhead are 5-10ft. lower than the corresponding feature across the river. This slope is still more strongly seen at East Slough and Langley, where there is even a suggestion that the ground at the southern boundary of the feature may be part of a minor sub-stage (T_1) at about 80-90ft. There are similar relics at this level on the south bank of the river east of Holyport.

The detailed topography of the terrace is of considerable interest, and stands in striking contrast to that of the flood-plain. The wide area of terrace around Slough and Langley consists in detail of swelling whalebacks of higher ground (at about 103-105ft.) on a general surface at about 100ft. Small as these seemingly trivial features are, they can in places be seen with the naked eye. They seem to coincide with the main brickearth patches, and the hollows are in many cases on bare gravel. On the flood-plain, on the other hand, the swelling "eyots" are all gravel-cored, and the softer alluvia occupy the lowest ground, in general that which is still occasionally flooded.

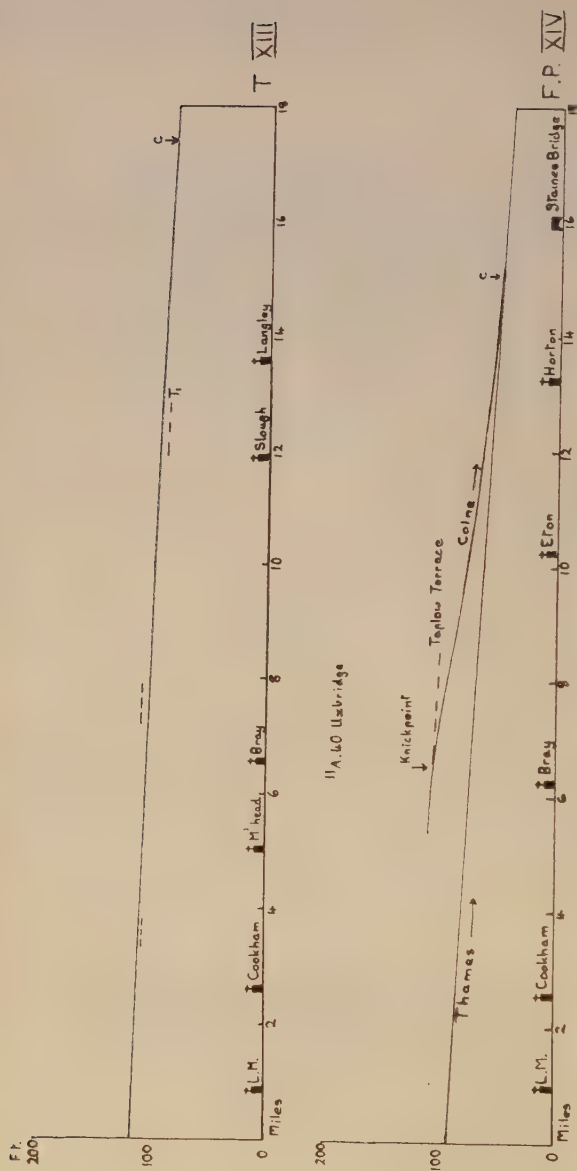


FIG. 32.—SECTIONS XIII–XIV.

Long-profiles of the Taplow (XIII) and Flood-plain (XIV) terraces of the Thames, uniform with Pl. 17. Section XIV also contains a section up the flood-plain of the Colne as far as the knickpoint near Uxbridge, beyond which the river still flows on the Taplow surface.

It may be noted here that the existence of a minor sub-stage about 10ft. below the general level is not considered to be enough warrant for a division of the terrace into two facets. The insignificant bluff separating the two at Slough and Langley is never more than a gentle slope, and the lower sub-facet is regarded in the same light as the similar anomalous patches of the Harefield and Winter Hill Terraces.

The bluff at the rear of the terrace is generally poorly developed, except where it is cut in Chalk, as in the west. It is very strongly developed at Taplow, where it is cut back to the Black Park Terrace. At Lent Rise it is no more than a gentle rise, from which the hamlet gets its name. It is wide and gently sloping north of Slough, and further east is clearly seen only at George Green and Love Hill. The bluff is cut in London Clay east of the Beaconsfield-Slough road, and as usual has been largely destroyed by gravitational erosion.

(viii) The Flood-plain Terrace

The modern flood-plain is, of course, continuous all along the present-day course of the river, since the latter passes over no knickpoint in this stretch. The flood-plain surface is well worth a detailed study, as it is in many ways a yardstick by which the older terraces can be measured.

At Bourne End the flood-plain is about three-quarters of a mile wide, and is bounded by steep Chalk cliffs. The general ground level varies from about 85ft. to 90ft., but Bourne End itself lies on a slightly raised surface at up to 95ft., probably on the "delta" of the Wye, which joins the Thames here. South of Bourne End the plain widens, and then narrows out again at Maidenhead, where the level is 75–80ft. The plain again widens east of Maidenhead and at Dorney is about $2\frac{1}{2}$ miles wide. It narrows a little at Eton, where the Chalk inlier of Windsor Castle has prevented free lateral swinging of the meander-belt. Eastwards from Eton it broadens rapidly, and at Wraysbury (Wyrardisbury) it joins the Colne flood-plain, which projects into the Thames flood-plain on a tiny, but distinct, delta of slightly raised ground. The spreading out of the Colne distributaries (Colne Brook, Frays, Colne, Yiewsley river, etc.) depends on this deltaic form. The level of the plain falls from about 75–80ft. at Maidenhead to 65–70ft. at Eton and 55–60ft. at Wraysbury and Horton, where the Colne delta comes in. The latter is about 5ft. higher in its centre than the flood-plain of the Thames immediately upstream.

The Colne flood-plain is, as might be expected, much narrower than that of the Thames, and has a steeper long profile. In the three miles from West Drayton to the Slough Road at Uxbridge the plain rises some 16ft., or about 5ft. a mile. The river rises another 50ft. in the next six miles, but it is highly probable the river passes over a knickpoint in this reach at about 115ft. (Wooldridge

and Kirkaldy, 1936) and that above this break of profile the river flows on the Taplow "Terrace."

The Thames flood-plain presents many interesting surface features, some of which can also be identified in the higher terraces. These may be considered in turn as follows :—

- (a) Transverse slope. In many places the flood-plain has a gentle southward slope in its east-west reach, i.e., the ground is slightly higher along the northern flank of the flood-plain than along the southern boundary. The net height difference may locally attain 8ft. No such slope is visible, however, in either the north-south reach of the river near Maidenhead nor in the Colne flood-plain.
- (b) Surface features. Apart from the transverse slope, however, there is considerable minor relief. The surface consists of low, gravelly hummocks called eyots, with intervening hollows now partially infilled with alluvium. At present the total difference in height between the two never attains 10ft., but were the alluvium removed the effective relief would amount to 15-20ft. in places. In other words, the gravel train has a braided surface rather resembling a very flat species of drumlin topography. This fact permits of several explanations. One is that the gravel surface was originally flat, but was eroded into its present form during a minor phase of downcutting by a dense network of small tributaries or distributaries; the alluvium may have been deposited during a subsequent quieter phase, probably by washing out of the gravel eyots. A more probable theory is that the surface of the gravels at the end of the phase of aggradation was braided as it is now. It is widely known that during active aggradation streams take up a braided channel rather than a meandering course. It is conceivable that the gravel eyots of the modern river represent the major braidings of a larger Thames during the aggradation.
- (c) Bluffs. Since they are the most recently cut, we should expect the flood-plain bluffs to be steep and fresh. In many cases they are, especially where they are cut in Chalk, as in the Maidenhead area. The eastern edge of the flood-plain between Maidenhead and Hedsor is an impressive cliff, in places almost vertical, running up to the Black Park Terrace, Winter Hill Terrace or even the Harefield Terrace. The river is here swinging laterally eastwards, and the cliff is still being actively undercut. Bare Chalk outcrops along the cliff, and rockfalls were fairly common until the cliff was planted. Other areas where flood-plain bluffs are especially well-developed are

at Windsor, where the Chalk inlier has a precipitous northern face due to the lateral erosion of the river, and at Coopers Hill, Egham. The latter is cut in London Clay, and the bluff is covered with landslips. The erosion here was so recent that the convexity of the bluff extends right to the base, notwithstanding landslips and soil-creep.

IV. THE MORPHOLOGY OF THE COUNTRY SOUTH OF THE THAMES

The fact that the river was shifting southward throughout the morphological stages described above, has meant that the country south of the river is here devoid of any traceable Thames terrace features, other than a few relics of Taplow and Lynch Hill age south of Maidenhead. It was nevertheless examined by the writer in the hope that some unexpected evidence might be revealed. The preliminary examination confirmed that the country is devoid of any trace of Thames terraces, thus establishing the already evident southward shift of the river.

Most of this southern landscape is maturely eroded, and few old surfaces are to be seen. A high terrace feature quite conspicuous in character is, however, traceable along an east-west line running through Laleham, Ascot and Warfield. If one stands on any of the higher ground in Windsor Great Park and looks south, it is clear that the Reading-Staines road runs along a shallow trough with a floor at between 210 and 230ft., though this is cut into by the deep and steep-sided tributaries of the Virginia Water stream, which follows the line of the higher valley. This trough stands in striking contrast to the hilly country to north and south. The floor of the valley consists of an old terrace of a larger ancestor of the present Virginia Water stream. The terrace has the smooth, almost flat surface typical of a flood-plain, though it is now cut into by subsequent erosion. Its former course is indicated on Pl. 14. The surface lies at about 235ft. near Warfield, and falls eastwards at about 4ft. a mile to a level of about 205ft. near Virginia Water station. It is quite smooth, and is underlain by a varying thickness of badly-stratified gravels, which are free of Bunter quartzites. It seems clear that this surface is the old flood-plain of a once considerable stream (since the plain is about 2,000–3,000 yards wide) draining eastwards from the country south of Reading. From its level and direction, it must have been tributary to the ancestor of the modern Wey somewhere near Staines or Feltham, probably in the Black Park or Winter Hill stages¹. This stream may once have collected the drainage of the Loddon and Blackwater systems.

¹ Incorrectly marked Lynch Hill in Pl. 14.

No other trace of old surfaces was found except further south in the top of the Chobham ridges, which are capped by a high platform. This lies south of the area surveyed, however, and will not be discussed here.

V. RECENT EROSION FEATURES

Pl. 13 shows that the great flight of terraces which make up the landscape is being slowly eroded by a series of minor tributaries of the Thames and Colne. In the east of the area covered by the map this erosion has removed more than half of the terraced landscape, and in places a state of mature dissection has arisen. Further west, however, dissection is still only youthful. This difference mainly arises from the difference in subsoil. In the west the subsoil is Chalk, and the terraces consist of gravel-covered benches cut in the hard and competent Chalk. The tributary valleys are here steep-sided, and have been slow to widen. Moreover, all the valleys are now dry, so that erosion has been suspended. In the east, however, the valleys are cut in the incompetent London Clay, and are now fairly wide. Erosion is still active. On the narrow intervening outcrop of the Reading Beds the dissection is still in progress, but the sandy beds encourage a more steep-sided valley cross-profile. The Reading Beds are, moreover, thin, and it is common for streams crossing them to find their way down through them into the underlying Chalk, and so disappear. The system of valleys converging near Burnham Station, for example (see Pl. 13) is largely dry, but intermittent drainage occurs in Burnham Beeches on the Reading Beds, the streams descending into swallets in several places along the valley floor where the Chalk is exposed. Drainage of the lower terraces is, as one might expect, simply dendritic, with a general direction towards the flood-plain. The Harefield and higher terraces are, however, drained by eastward-flowing streams like the Alder Bourne and Misbourne (see Fig. 32). North-west of Farnham Common there is an example of minor river-capture; headward recession of a north-south valley (one of those converging near Burnham station) has captured an east-west head-valley of the Alder Bourne. Both streams are now dry.

Little can be learned from the long-profile of these valleys. Judging by the uninterrupted profile, without obvious knickpoints, flow proceeded in the now dry Hitcham dry-valley when the flood-plain of the Thames was at its present level, to which the valley appears graded. The same is true of the valleys converging on Burnham station, though in this instance some of the tributary valleys distinctly "hang." There is historical evidence for flow along some of these now completely dry valleys, and the old stream-bed can be seen in places. It is fairly obvious that the water-table

in the Chalk was much higher than at present in very recent times, when the Thames was already at its present level. The long-profile of the dry-valleys is in places reversed, indicating temporary flow up-valley towards swallets.

Some of the minor streams in the country north and north-east of Slough have short stretches of flow along the Taplow Terrace. The knickpoint at the head of the reach graded to the flood-plain has not yet cut back across the Taplow Terrace, so that erosion of the higher terraces is still the work of streams graded to the Taplow Terrace.

Solution features are of some interest. They are principally of the "swallet" type, and are widely scattered over the Chalk and Reading Beds country. In general the features fall into the following classes :—

- i. "*Dimples*" on bare Chalk surfaces. These are neat little depressions about 5–15 yards across, and up to 25ft. in depth. Usually circular, they have the regular form characteristic of all Chalk terrains. They occur mainly on steep slopes, chiefly valley sides. They are probably abandoned swallets of the valley side class discussed below, and date from a wetter period when surface water was more abundant.
 - ii. *Valley side "swallets."* These are small, sometimes deep depressions found on Chalk valley sides or on bluffs cut in Chalk. They occur just at the junction of the gravel cap of the terrace with the valley-side Chalk, or at the junction of the Chalk and Reading Beds. Many of them serve today to collect the rivulets which drain off these capping beds on to the Chalk. A very fine series occurs along the Wye valley, on the eastern flank, where flow off the rather structureless, loamy gravel of the Harefield Terrace is quite considerable in winter.
 - iii. *Valley floor "swallets."* A succession of dry or active swallets is found along the floor of most of the dry valleys. Some of these are small and smooth-outlined, but others are large, cavernous structures descending as much as 40ft. below the general ground level. The base of these deep structures, locally called "pots," often shows signs of recent subsidence ; two such collapses occurred within the experience of the writer. The larger type of swallet may be 50 yards or more across, and usually has a complex outline and a very uneven floor. They are usually filled with trees, as it is impossible to cultivate them, owing to their steep sides.
- Excellent examples of both dry and active swallets occur in the deep valley cutting through Burnham Beeches.

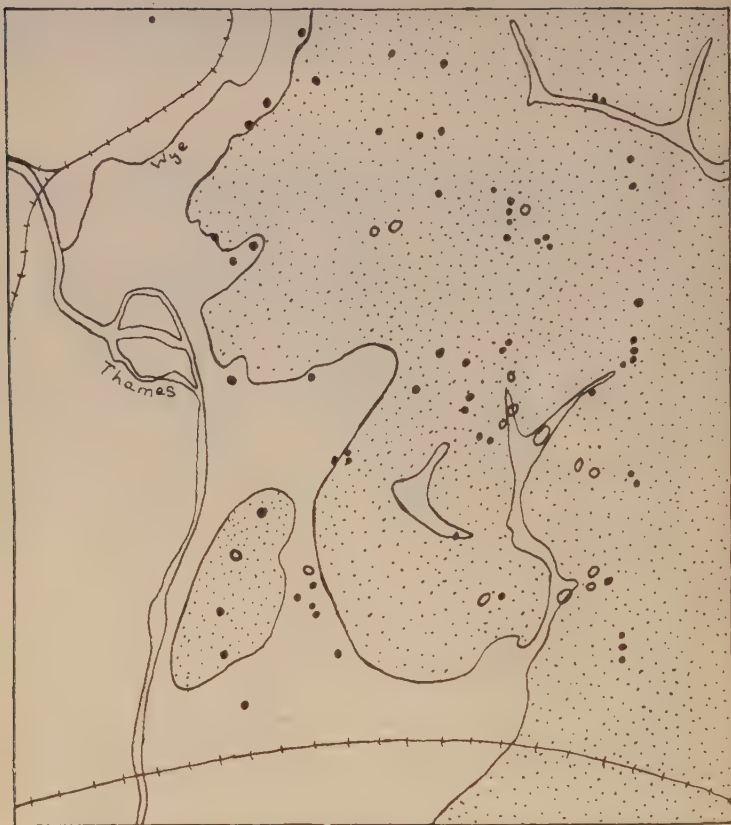


FIG. 33.—THE LARGER SOLUTION FEATURES IN THE COUNTRY ROUND BURNHAM

This map includes the valley side and valley floor swallets both dry and active, but omits the smaller "dimples" on the bare chalk. Note the concentration of swallets near the Reading Bed (dotted)–Chalk (plain) junction. The greater fraction of the swallets within the Reading Beds outcrop occur where the chalk is very close to the surface, but some appear to be developed on close to 40ft. of Reading Beds. The larger, cavernous structures referred to in the text are indicated by small rings roughly indicative of the shape of the feature. These larger swallets occur chiefly along the valley draining Burnham Beeches.

Fig. 33 shows in summary the disposition of these solution features. As might be expected, they are concentrated near the Reading Beds–Chalk junction, where an abundance of surface water is available for their formation. They sometimes occur, however, within the Reading Beds outcrop, indicating the occasional complete failure of the clay horizons near the base of that stratum.

VI. DISCUSSION OF EVIDENCE

The detailed evidence presented in the foregoing sections needs some further discussion in order to bring out its real significance. The claim has been made that the morphological evidence is clear enough to allow reasonable certainty as to the mode of origin of the landscape and of the Stage II and III drifts, and that this evidence alone can do what the archaeological, palaeontological and petrographical methods have failed to do—i.e., to provide a reasoned picture of the evolution of the modern Thames drainage system. This ambitious claim needs examination, as it rests on certain assumptions which have not so far been critically studied. In this section, therefore, a double task will be undertaken; first, to see what evidence there is for assuming that the surfaces described above are in fact river terraces, and second, to summarise the stages in the evolution of the Thames drainage in the light of the evidence.

General Characteristics of the Terraces.—Proof that the features here described are old terraces of the Thames must come mainly from a comparison with the lowest terraces, whose character is not in dispute. The following account deals with the main physical characteristics of the terraces in turn, and in each case it will be shown that the terraces of the Stage II drift-belt resemble those of Stage III :—

1. *Longitudinal slope.* All but one of the terrace features described slope eastwards at rates similar to, but not identical with, those of the Boyn Hill, Taplow and Flood-plain terraces. The exception, the Winter Hill, has little slope, and this fact may have been due to prolonged aggradation in a ponded-up valley. All the remaining terraces slope downstream at rates between two and four to five feet a mile. These facts show up clearly in Figs. 31–32 and Pl. 17, which include long-profiles along each terrace. Owing to the change in form and direction of the valley floor during the construction of those terraces it is not possible to show all these profiles on a single diagram, but it is clear that the higher terraces, like the lower, form high platforms along the modern valley sides, falling eastwards at much the same rate as the modern flood-plain. This seems to be good evidence that they are themselves old flood-plains of the river, and that they have been left suspended during the subsequent downcutting. It is also reasonably clear that there has been no important tilting or warping of the terrain, or the rough parallelism of the features would have been utterly destroyed. This was assumed to be true at the outset of the work, but it soon became clear that the assumption was well founded. The evidence is all in favour of successive rejuvenations without any differential tilting or warping.

2. *Mode of origin ; spacing of terraces.* Ross (1931) and Wooldridge (1938 *et. al.*) concluded that the Winter Hill Terrace and the Lower and Higher Gravel Trains were "cut-and-built" terraces, the essential formative steps being as follows : (i) a phase of downcutting : normally this would mean the incision of the meander-belt into its flood-plain, followed by the cutting of a plane of erosion by lateral corrasion at the end of the downcutting ; (ii) a phase of aggradation, in which gravels, alluvia or brickearths were accumulated on the new flood-plain. When aggradation ceased, the river flowed on the "terminal surface," which on fresh rejuvenation became the new terrace. It is worth noting that the flood-plain could be widened during the aggradation, since lateral corrasion would not be hindered thereby. The writer agrees with this general picture, though with certain reservations ; there can be little doubt that the terraces represent seven successive rejuvenations and subsequent aggradations, of which they are the terminal surfaces. A remarkable fact that emerges from the study, however, is that these rejuvenations appear to have been rhythmic ; there is a regularity in the spacing of the terraces that might not be expected on general grounds. Table I indicates this regularity.

TABLE I. HEIGHTS OF TERRACES AND OF UNDERLYING ROCK PLATFORMS ON MERIDIAN OF SLOUGH

1 Terrace	2 Ht. of terrace (approx.)	3 Thickness of drift (approx.)	4 Total rejuvenation	5 Net inter-terrace fall (i.e. bluff size)
Upper Gravel Train	375 ^z	—	—	—
Harefield ...	310	10	75	65
Winter Hill ...	260	15	65	50
Black Park ...	210	10	60	50
Boyn Hill	175	20	55	35
Lynch Hill ...	130	10	55	45
Taplow ...	100	10	40	30
Flood-plain ...	65	20-30	55-65	35

In this table column 2 gives the approximate height of the terminal surface north or south of Slough, and column 3 gives typical figures for the thickness of the associated drift-trains. These figures combined give the level of the rock-platform underlying each terrace. Column 4 then gives the total height difference between each terrace surface and the level of the rock-platform

^z Facet at Beaconsfield Church.

of the next terrace below. These figures are hence the full measure of the downcutting that separates the terraces. It is seen that the extent of the rejuvenation has fallen off fairly regularly from 70ft. in the pre-Harefield erosion to some 40ft. in the pre-Taplow phase. The Flood-plain stage was, however, preceded by a much more severe downcutting, now evidenced by the much greater thickness of the drift. Column 5 gives the height-difference between successive terminal surfaces—i.e., the height of the bluffs between the terraces. Here the figures represent the difference in level between successive aggraded, quiescent phases in the river's development. Again, there is a fairly uniform decrease in the magnitude of successive falls, although the abnormally heavy aggradation of Boyn Hill gravels disturbs the regularity to some extent.

Table I suggests a rhythmic oscillation of base-level, with the amplitude of the oscillation being slowly damped down with time. To what extent this apparent rhythm is illusory it is difficult to say; it may well be that the terraces do not quite maintain their evenly-spaced character all the way along the valley, and that this regularity is an accident of position. This, however, may be doubted; the small differences in gradient that exist between the terraces are enough seriously to change their relative levels if these differences persist far up or down-stream, but this is probably not the case in the field. It would, however, be unwise to attach any sort of certainty to this impression of a regular oscillation of base-level as long as it rests on an analysis of so small an area.

It may be noted in passing that the figures given in Table I indicate that the solid rock underlying the terraces should outcrop on all the bluffs, all of which are considerably higher than the drift-trains are deep. The outcrop of the Chalk, Reading Beds or London Clay can in fact be traced on all the bluffs in places, but in some areas the wash from the overlying terrace-gravels obscures the solid. This is especially true of the wide, gentle bluffs cut in London Clay in the east; many of these slopes (such as that north of Iver) are entirely covered with wash or even some feet of contorted or structureless gravel. Nevertheless it is clear that the terraces are gravel-covered benches, and not benches cut in gravel.

3. *Cross-profiles and uniclinal shift.* Frequent reference was made above to the fairly strong transverse or cross slopes of the terrace features. The cross-profile normally has a slope riverwards (i.e., in most cases southwards), but in some cases the southern lip of the terrace is actually higher than the part of the surface underlying the terminal bluff. Thus the highest ground of the Black Park Terrace near Taplow is at about 220ft., right at the very lip of the terrace. The ground then falls northward to about 211ft. a mile to the north. This may in part be due to the removal of the drift-cover by sub-surface drainage, which is here very active, but the case is not an isolated one. We have, therefore, to account

for distinct cross-slopes on the terraces that usually exceed the longitudinal slope ; these cross-slopes may, we have seen, be directed either towards the lip or the back of the terrace.

A heavily aggrading stream normally flows on a pile of natural levees raised some feet above the general flood-plain level. Hence it might seem reasonable to suppose that the normal slope of a surviving terrace-relic should be northwards, i.e., away from the position of the river at the end of the phase of aggradation which produced the terrace. Such, however, is the exceptional case, as was indicated above. The slope is far more often southward than northward, and may exceed 5ft. a mile in places. This is partly due to the piling up of downwash from the bluff on the rear of the terrace ; in places this can be proved by the exposure of contorted solifluction gravel overlying the terrace drifts themselves. But one nevertheless gets the impression that several of the terraces have a real riverwards slope bound up with their mode of formation. Between Maidenhead and Eton, for example, this is true even of the flood-plain.

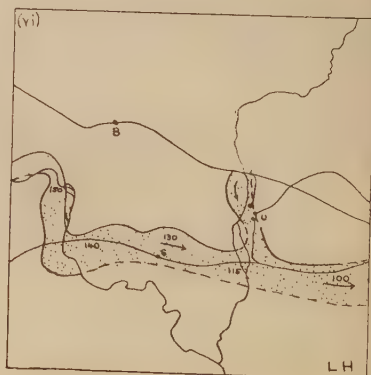
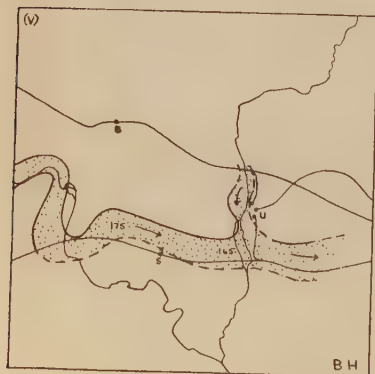
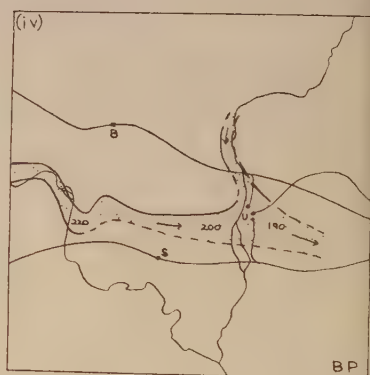
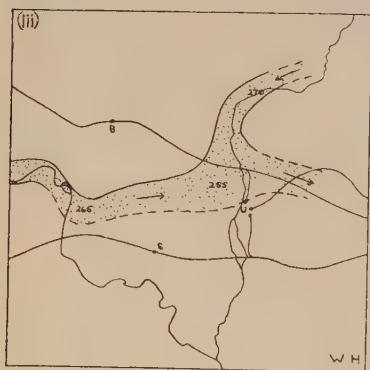
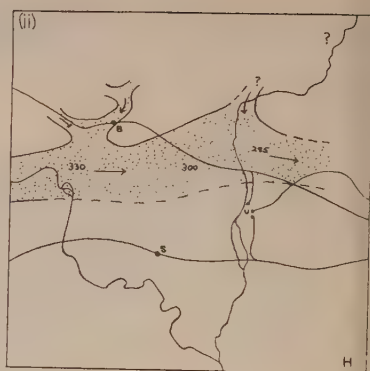
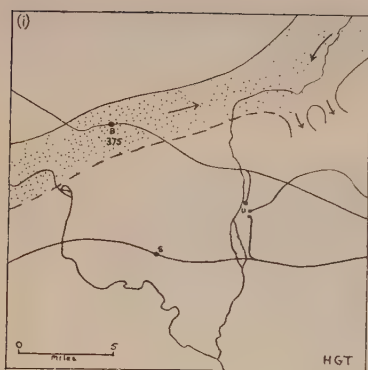
It is to be recalled that the terraces were here formed by a river that was slipping laterally southwards. This was partly the result of uniclinal slip during the phases of downcutting, and probably also due to the piling up of debris in the Thames flood-plain by the pro-glacial Colne and other melt-waters. This shift has been responsible for the wide-preservation of the terrace relics, which have survived here solely because the river has rarely tended to swing northwards during its periods of lateral erosion. In the Henley-Bourne End reach, by contrast, the Thames has remained in essentially the same position throughout its history, and each successive flood-plain has tended to cut its predecessor away. It might be argued from this fact of southward shift that the staircase of terraces north of Slough are not cut-and-built rejected flood-plains at all, but are meander-cut terraces on a slip-off slope. At first sight the transverse slope of the terraces towards the river might be considered to support this view. The Boyn Hill Terrace, for example, is at heights from 165–170ft. near Maidenhead, and from 175–180ft. north of Lent Rise, a mile downstream. The terrace hence does not “ pair ” too well across the river. The same is true of the Taplow Terrace. A moment’s reflection will show, however, that the fact of southward slope is against this argument ; the cut of a meander is necessarily flat, in the transverse sense, even though it is made during a phase of marked downcutting. The Stoke Park Cut is remarkably flat, and shows no sign whatever of transverse or cross-slope, despite the 7ft. a mile longitudinal slopes. A second argument concerns the drift-cover. How can up to 20ft. of bedded gravel accumulate on a meander-cut terrace ?

We are, therefore, confirmed in the view that these gently-sloping terraces are essentially of the cut-and-built class. Wooldridge

(1938) has written, "there is . . . a strong suggestion that even during major phases of aggradation the river continued to move 'down dip.' " The present writer is inclined to feel that this seemingly paradoxical view is too pessimistic ; the slope of these features is, after all, small, and the difference of level between the rear and lip of the terrace is quite negligible by comparison with the intervening bluffs. The modern Thames flows in a wide meander belt along the southern flank of the flood-plain ; it is in places actively eroding its bluffs by lateral corrasion. Yet the flood-plain surface is obviously a terrace terminal surface, bounded by clearly marked bluffs : so must things have been with the higher, earlier flood-plains in its history. We may note that the cross-slope of the flood-plain is good disproof of the view that the slopes are due to a gentle southward tilt following a depression of the main syncline to the south ; the flood-plain is as much affected by cross-slope as the Boyn Hill or Harefield Terraces, and it is inconceivable that so considerable an epeirogenetic movement could have occurred since the main flood-plain aggradation.

4. *Processes of waste and decay.* The destruction of the terrace relics by subsequent erosion has already been discussed. It was shown that they have been attacked by minor tributary valley development and also, in the Chalk area, by sub-surface solution. The terraces cut in the Chalk are in fact in the earliest stage (doline phase) of destruction by the processes of the Karst cycle. The more immediate effect of the Chalk, however, has been to protect rather than to destroy the terraces. The sub-surface drainage will, if long enough continued, eventually destroy the terrace surfaces by sapping from below, but so far the terraces have in fact gained by being protected from the far more active surface erosion. The terraces are hence best preserved on the Chalk outcrop. Processes of waste and decay inherent in the form of the terraced landscape itself are largely confined to the bluffs. These initially steeply sloping facets have been subject for varying periods to the action of soil-creep, land-slip and other gravitational processes of decay. Much of their original steepness has vanished, and a trail of down-wash spreads out across the terrace beneath at the foot of each of them. Fig. 35 gives a cross-section of the Black Park-Boyn Hill bluff at Burnham Beeches reconstructed from actual exposures showing the drift-structures.

It may be noted in passing that the condition of these bluffs in no way supports W. Penck's (1924) theory of the development of "haldenhang" under-talus slopes, and of the parallel retreat of slopes. In Penck's view, once the mechanism for removal of talus has ceased (as it does on these terraces when the river cuts into their floor and leaves their surface dry) the talus accumulates on a rock-cut surface, the "haldenhang," as the declivity retreats ; in other words, the effect of gravitational wastage of slopes is to create less



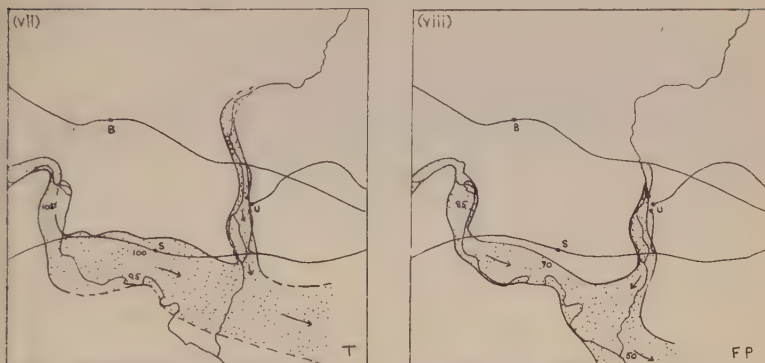


FIG. 34.—PALAEOGEOGRAPHY OF THE EIGHT MAIN STAGES IN THE DEVELOPMENT OF THE MODERN DRAINAGE SYSTEM.

On each map the G.W.R. main lines from London to High Wycombe and Reading and the L.P.T.B. Uxbridge line are indicated, together with the positions of the stations at Beaconsfield (B), Uxbridge (U) and Slough (S). The modern courses of the Thames and Colne are also shown. The flood-plain stages are indicated by the dotted bands, which show in some detail the change in the courses of the rivers. The approximate height in feet of the flood-plain is given by the black figures.

Key to the figures :—

- (i) Higher Gravel Train (after Wooldridge).
- (ii) Harefield.
- (iii) Winter Hill.
- (iv) Black Park.
- (v) Boyn Hill.
- (vi) Lynch Hill.
- (vii) Taplow.
- (viii) Flood-plain.

steeply sloping talus covered slopes. As the original slope retreats, it retains its angle of slope throughout. Hence the overall relief of a bluff during such a wasting process is concave upwards, the rear part being the steeply sloping remains of the initial bluff, still retreating, and the front part being the talus strewn "haldenhang." In practice the bluffs have quite a different form. The upper half of the slope is always convex upwards, and the lower half is concave. The change of sign of the curvature is never very far from the middle-level of the bluff. We may hence conclude that the waste processes acting on these bluffs tend to reduce its slope without causing it to retreat, and that the bluffs stand today where they were originally cut, though they are now wider and less steep.

It may be noted that the broadening process may continue so long that the foot of one bluff may reach out until it meets the lip of the next below, completely removing or hiding the intervening

terrace-relic. There is little doubt, for example, that terraces were once distinguishable in the now continuous gravel-covered slope north of Richings Park (Iver). The London Clay, with its wet, slippery surface especially favours such union.

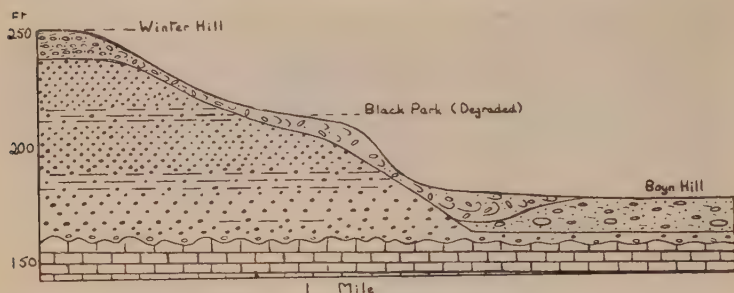


FIG. 35.—SECTION ACROSS THE BLUFF ABOVE THE BOYN HILL TERRACE AT BURNHAM BEECHES, which rises to the Black Park Terrace (degraded) and the Winter Hill. The bluff is cut in about 75ft. of sandy Reading Beds with two clear cut clay bands. Much of the bluff is covered with contorted solifluction gravels, which have accumulated at the rear of the terrace slightly raising the ground level. The solifluction gravels at this point, however, are some 10-15ft. thick, and their base descends well below the general terrace-top level, suggesting that they were in part contemporary with the aggradation of the Boyn Hill Gravels. The latter here contain very large, little-worn boulders, chiefly of sarsen, but some of varieties of very hard quartzite.

Exposures:—East Burnham Common (well-bedded Winter Hill Gravels); Seven Ways Plain (on bluff itself, showing trail); Wingroves Tea Garden (showing 10-15ft. contorted solifluction gravel overlying well-bedded Boyn Hill Gravel); and the lower Wingrove Pit, showing the undisturbed Boyn Hill.

Fig. 34 summarises the palaeogeography of the Thames and its tributaries in the region under discussion insofar as the evidence presented here will permit us to go. These are self-explanatory, and no further comment is thought necessary. They trace in detail the evolution of the bend at Bourne End, of the movement of the Thames-Colne junction, and the general physiographic history of this part of the Thames valley. They are the final synthesis of all the results collected in this paper.

DISCUSSION

Dr. K. P. OAKLEY congratulated Professor Hare on his masterly elucidation of the morphology of the terraces of the Middle Thames. He said that he was inclined to advocate the adoption of the term Lynch Hill Terrace for the feature which contained the Iver and Furze Platt gravels. Mr. Lacaille, to whom great tribute was due for his work in this region, had shown that these two gravels contained different cultural assemblages. They appeared, moreover, to be lithologically distinct. Yet it was evident that they now had a common terminal surface. The speaker, in conjunction with Professor King,

had suggested in 1936 that the explanation might be that this surface (like the Stoke Park Cut recognised by the author) transected deposits of more than one age. He had restricted the term Iver Terrace to that part of this apparently composite terrace which contained gravels with a particular lithology and archaeological content. A terrace intermediate in position between the Boyn Hill and Taplow Terraces was now recognised in many regions, but it was confusing to call it everywhere the Iver Terrace, and a new term was desirable.

It was obviously important to distinguish clearly between terraces (as morphological units) and the deposits which composed them. The speaker said that he was less confident than he was in 1936 about the value of palaeoliths for close dating, in view of the cultural complexities within the Lower Palaeolithic, which recent studies had revealed. Nevertheless, if two gravels contained different palaeolithic assemblages it was necessary to recognise the possibility that they were of different ages. In the present case it seemed desirable to use a double nomenclature. Thus the terrace deposits at Iver could be described as Lynch Hill Terrace (Iver Stage), and those at Furze Platt, Baker's Farm, etc., as Lynch Hill Terrace (Furze Platt Stage). The term Iver Terrace was ambiguous and had better be dropped. The terms Taplow and Boyn Hill should be reserved for the terrace nomenclature and not used to designate gravels of particular ages.

Mr. WRIGLEY noted that Harefield is now used to define a terrace of Pleistocene drift although it is well known as a locality for Eocene fossils in an instructive section which has been described in several publications. It might be better to choose a place-name which, like Twyford or Boyn Hill, will not suggest anything but Pleistocene deposits.

He remarked that when terraces were delimited, a presumption arises that each of them represents a definite time-phase. This may not be so. In the Lea valley the flood-plain, beneath an uniform level and at similar depths, there are relics of a tundra in Arctic plants, mollusca and vertebrates, while in another place a buried peat yielded clear evidence of a temperate flora like that of our own present day N. Midlands. Nothing in the surface aspect of these Lea gravels suggests such a discrepancy, which involves a long interval of time and a large change of physical conditions.

Mr. STEBBING, in referring to the highest level deposits about Beaconsfield, asked if any difference in the materials forming the terraces had been noted, and of the flood conditions which had laid down such a succession. The river systems, which were evidenced by these gravels, were one aspect of an interesting subject.

Professor S. W. WOOLDRIDGE expressed his great appreciation of the paper and his sense of its importance. His one regret was that the exigencies of the wartime years had made it impossible for him to spend more time with the author in the field, but he was glad to find occasion to say that Professor Hare's work, while confirming his own findings in many particulars, had extended, consolidated and corrected them in very important degree. In this paper the view that the "Plateau Gravels" were veritably "Terrace Gravels," first advanced by H. J. Osborne White and adopted by many successors, found its most complete, convincing and accurate demonstration.

One point alone might prove controversial. The view tentatively proposed by King and Oakley in 1936, that the Clacton and Ilford stages were to be chronologically intercalated between the Lower and Middle Barnfield "leaves" of the Boyn Hill Terrace at Swanscombe called for bigger oscillation of base-level than any advanced in the paper. It should be noted, however, that morphological methods could not by their very nature be taken as entirely disproving the indications of "Zonal Typology." Substantial aggradation might bury a "cut bench" and replace it at a higher level by a terminal surface of later date. While, however, this remained a possibility, the bearing of the author's results taken as a whole, rendered this at least an unlikely picture of the course of events in the Middle Thames valley. The remarkable similarity of the terrace features seemed to imply a spasmodically dropping base-level, uninterrupted

by positive movement large enough to invert the physiographic sequence of deposits.

The AUTHOR wished to thank those who had contributed to the discussion of his paper. He agreed with Dr. Oakley that there might be other erosion features similar to the Stoke Park Cut. He could not, however, see how bed-rock could outcrop on the bluff between Boyn Hill and Lynch Hill surfaces if the lower surface was merely a cut into the same gravel train. He agreed that the enigma of the artefacts was one urgently requiring solution, and hoped that Messrs. Oakley and Lacaille would be able to examine the ground again. Dr. Oakley's second point seemed to him of considerable importance; it rested on the same assumptions as Dr. Wrigley's comments on the composite character of the drift underlying the Lea Flood-plain surface. It might very profitably be agreed to restrict the terms "Taplow," "Boyn Hill," "Winter Hill" to the upper surfaces of the corresponding gravel trains, or in other words to give them a purely morphological significance. It was doubtful, however, whether so strongly entrenched a nomenclature could be restricted in this manner. Furthermore, there was a danger that such methods would lead to the assumption that the morphological evidence could be kept distinct from evidence adduced from other fields in a final synthesis. If, however, Dr. Oakley's suggestion met general approval, it would help to avoid the equally undesirable view that a morphological feature was necessarily a chronological unit.

In reply to Mr. Stebbing, the author said that he had been unable in the time at his disposal to correlate the drift and the morphology as well as he would have wished. On each of the terraces well-bedded gravels of typical fluvial type occurred in places, and on several there were signs of torrential and highly irregular flow—especially in the Boyn Hill drifts.

The point raised by Mr. Wrigley concerning the use of the name "Harefield" for a terrace seemed to the Author to carry some weight: since, however, there was no other settlement of appreciable size on the feature there was no reasonable alternative; he felt that a terrace's name should be chosen rigorously from settlements actually on its surface. Both H. J. O. White and Mrs. B. R. M. Ross had proposed suitable names for what seemed to be the corresponding feature in the Kennet valley, but until detailed mapping linked the two areas it would be improper to adopt either worker's term.

The author thanked Professor Wooldridge for his comments as regards the limitations of the morphological evidence as the key to Pleistocene chronology and the movement of base-level. Though it was true that aggradation might bury a pre-existing bench, and leave a "terminal surface" of later date *above* the older bench, it was highly improbable that the older surface would ever be exhumed, since this would require that a new plain of lateral erosion should be cut at precisely the same level. The Author regretted very much that war conditions had prevented him from examining the evidence from the Lower Thames at close quarters before leaving for Canada.

The paper by Mr. J. F. N. Green (P.G.A., vol. lvii, 1946, p. 82) on the Terraces of Bournemouth (Hants) was not available to the author when he was preparing the present work. Interesting parallels arose between the two sets of results. Green recognised the same number of stages above the Upper Taplow (Iver Terrace) as were distinguished by the author above the Lynch Hill. A rough side-by-side comparison of results was as follows:—

BOURNEMOUTH AREA (Green)		MIDDLE THAMES AREA	
Feature	Level Near Sea ¹	Feature	Lowest observed level in surveyed area ¹
1. Sicilian Terrace (Marine)	300ft.	1. Upper Gravel Train (Fluvialite) ...	340ft.
2. Upper Ambersham Terrace (Fluvialite) ...	250ft.	2. Harefield Terrace ...	280ft.
3. Ambersham Terrace ...	200ft.	3. Winter Hill Terrace ...	245ft.?

¹ Above sea level.

4. Sleight Terrace 165ft.	4. Black Park Terrace ... 190ft.
5. Boyn Hill Terrace ... 120ft.	5. Boyn Hill Terrace ... 165ft.
6. Upper Taplow (Iver) Terrace 90ft.	6. Lynch Hill Terrace ... 125ft.

Below this level a direct comparison was impracticable because of the complexity of the Bournemouth results. The above correlation resembled that given by Green on p. 93 of his paper. It had to be noted, however, that Green regarded the Upper Ambersham as a transitory stage, whereas the Harefield Terrace was one of the best developed of Thames terraces. Such correlations were highly tentative, and certainty could only come with further research.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Professor S. W. Wooldridge for his unbounded guidance and assistance in the preparation of this paper, particularly in the way in which he put his encyclopedic knowledge of the literature at the author's disposal, and also for reading it to the Association. Thanks are also due to Dr. E. C. Willatts for advice on the reproduction of the maps.

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THE AGE AND ORIGIN OF THE THRUTCH GORGE, N.E. LANCASHIRE

By V. DEAN and F. HODSON, F.G.S.

[Received 7th February, 1947]

THE THRUTCH GORGE.—The short, but imposing-looking gorge in the upper Irwell Valley, known locally as the “Thrutch” (Plate 18), is situated on the south-eastern outskirts of Waterfoot, Rossendale, in the county of Lancashire.

Over a quarter of a mile in length, the gorge is about 120ft. deep, and is barely wide enough to accommodate both the River Irwell and the main road from Waterfoot to Bacup. The gorge is excavated in the base of the Lower Haslingden Flags [1*] (Second Millstone Grit) and the underlying shales, and over a wide area hereabouts the beds have a low northerly dip. In the vicinity of the gorge the beds are not disturbed by faulting or other structural weakness to which the feature might possibly be attributed. The rocky walls and floor of the gorge yield no trace of ice action, though at the top the eroded surfaces of the rocks are overlain with Boulder Clay. The relationship between the drift and the solid rock on opposite sides of the gorge is significant, for as shown by the Section (Fig. 36) the rapid northerly slope of the eroded surface of the grits across that feature is accompanied by a corresponding thickening of the overlying clay in the same direction. Moreover, in the country south of the gorge, exposures of solid rock may occasionally be seen beneath the thin drift, while to the north of the gorge grits and shales are not met with again *in situ* for a distance of nearly half-a-mile.

These facts suggest that a substantial Pre-Glacial valley, now buried under thick drift, probably exists in the country immediately north of the gorge. There can, of course, be little doubt that the gorge has been cut by the River Irwell, for the stream is still actively engaged in deepening this feature. In these circumstances it seems highly probable that the Thrutch Gorge owes its origin to obstruction during Glacial times of the original valley, and the consequent displacement of the Post-Glacial drainage of the Irwell to the south of the ancient valley, i.e. along the course of the gorge.

THE IRWELL VALLEY EAST AND WEST OF THE THRUTCH GORGE

East and west of the gorge the valley of the Irwell is comparatively wide and spacious, and alluvial flats up to a sixth of a mile in breadth have been formed on Boulder Clay.

* For list of References see p. 344.

Numerous exposures, both natural and artificial, show that the southern slope of the valley is everywhere composed of flagstones and shales, overlain by a few feet of Boulder Clay.

On the other hand, the northern slope is entirely composed of thick deposits of Glacial drift, except for the grits forming the northern wall of the gorge. The relationship between the drift and the solid rock may be seen at both ends of the northern wall of the gorge, but more especially at the eastern end. Here, the widening of the valley at the expense of the drift has been accompanied by denudation in a down-stream direction. This process has led to the excavation of a wide semi-circular embayment in the thick drift behind the solid northern wall of the gorge. Here, then, we have direct evidence of the existence of a buried Pre-Glacial valley north of the gorge, and the embayment is obviously cut in its southern margin.

Farther east, the prevalence of thick drift along the northern side of the valley is indicated by numerous exposures of sand and clay, by occasional landslips, and by large hummocks of sand near Glen Top and Waterbarn. The deposits consist of Boulder Clay and overlying Sand and Gravel. A particularly fine bluff near Fearn's shows thick sand resting on clay, the total thickness down to the level of the Alluvium being well over 100ft. Exposures along the foot of Sow Clough, and farther east between Huttock End Farm and Bacup Road, show that the thick drift is not confined to the steep slope of the valley but extends some distance north of it. It is evident, therefore, that these deposits form a broad, irregular terrace of thick drift all along the northern side of the Irwell Valley. The drift-terrace is obviously continuous with the deposits in the buried valley north of the gorge, but, as we shall see later, it is more especially related to the drift which occupies the northern side of that ancient feature.

Except where it invades the head of Sow Clough, the northern boundary of the *thick* drift, and of the drift-terrace, occurs along a line extending westwards through Huttock End, and Piper Bank, to a small disused quarry south-west of Edgeside Park, on the north-eastern outskirts of Waterfoot. Along the northern side of the boundary the steep ground, which is in fact the true northern slope of the Irwell Valley, though still covered by occasional patches of thin drift, is shown by frequent outcrops to be composed of Upper Millstone Grits. South of the boundary line, excavations on the new housing site near Huttock End have yielded a more or less continuous section across the drift-terrace. Between the base of the drift-terrace slope and the farm at Huttock End the excavations were all in thick sand and gravel. Beyond the farm the cuttings were all in the underlying Boulder Clay. From this point the clay rapidly thins eastwards to disappear under the sand. To the west, its outcrop increases in breadth, and in the vicinity of

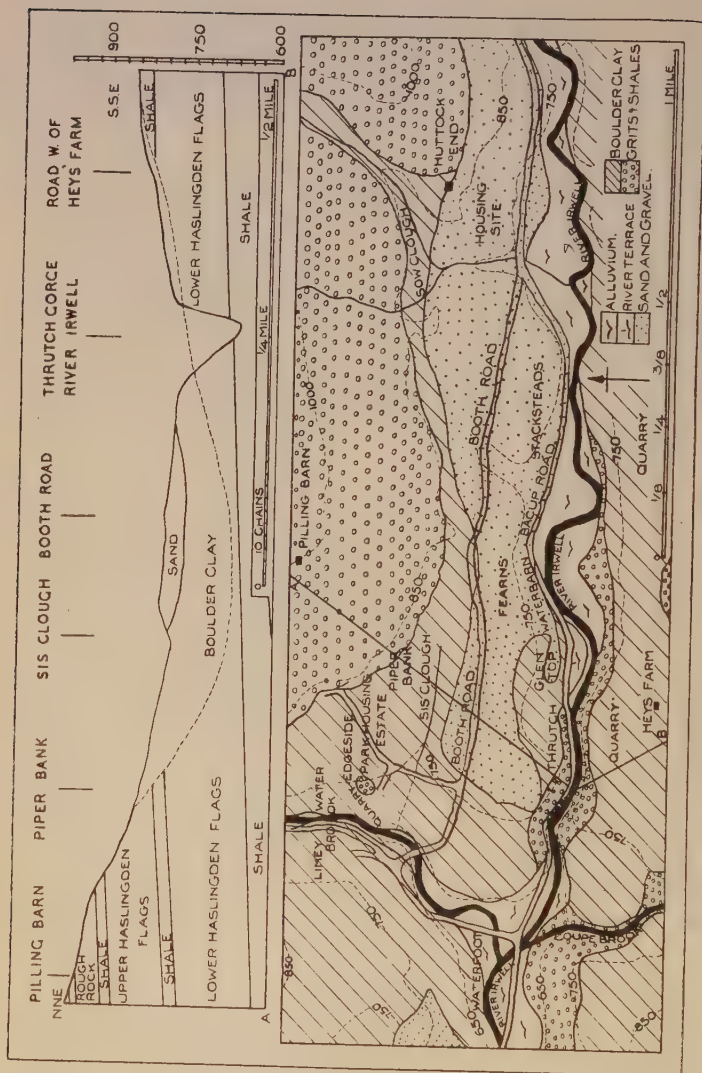


FIG. 36.—GEOLOGICAL SKETCH-MAP AND SECTION OF THE THRUTCH GORGE.

Piper Bank and Sis Clough the Boulder Clay has a spread of about one-sixth of a mile (see Sketch-Map and Section, Fig. 36). Conversely, the comparatively thin sand south of Sis Clough gradually thickens eastwards, and is continuous with the thick deposits of that material described above [1, 72, S.E.]. The thick deposits of drift which occupy the southern half of the buried valley have no equivalent in the valley of the Irwell south and east of Waterbarn. Nevertheless, there can be little doubt that at the close of Glacial times the upper reaches of the Irwell Valley were completely choked with drift up to the maximum height (about 900ft. O.D.) of the residual drift-terrace. It is evident, therefore, that the deposits which formerly corresponded with those in the southern half of the buried valley have been removed by the Irwell during Post-Glacial times. Thus it is only in the country north of the gorge, where the soft drift has been protected from the corasive action of the stream by the grits of the northern wall, that the Glacial deposits have been preserved; and the ancient valley still remains completely blocked. The axis of this Pre-Glacial valley is now represented by the westerly trend of the steep drift-slope east of Stacksteads, and thence along the line of Booth Road, to Waterfoot.

The evidence for the occurrence of the buried valley along the steep easterly slope of the Limey Water valley (see Sketch-Map, Fig. 36) is much obscured by large built-up areas. Nevertheless, the wedge-shaped outcrop of grits at the western end of the gorge is seen to pass beneath thick drift, and solid rock is not seen again until the old quarry near Edgeside Park is reached about one-third of a mile farther north. The higher slopes are rather hummocky, and yield evidence of occasional small landslips. Good exposures of thick clay have been seen on the new Edgeside Housing Estate and in Sis Clough, and sand is exposed along the southern slope of the latter feature. Indirect evidence regarding the composition of this slope is furnished by the occurrence of another terrace of thick drift, which extends along the northern side of the Irwell Valley between Waterfoot and Rawtenstall. The terrace is in every way comparable with the one east of the buried valley, and the three features are all in perfect alignment. It is evident, therefore, that at the close of the Glacial Period the Waterfoot-Rawtenstall drift-terrace was connected by thick deposits of drift at the foot of the Limey Water Valley, to the western end of the buried valley. Indeed, there can be little doubt that at that time this part of the Irwell Valley (like the upper reaches east of the gorge) was completely blocked with glacial débris.

East of the gorge the drift deposits are often seen to descend to the present level of the stream, and for this reason the base of the buried valley on the Section (Fig. 36) is assumed to be at that level. In this connection, however, it should be noted that a short distance

north of the Bacup Road, near Ilex Mill, Rawtenstall, and about one mile west-north-west of the gorge, a boring (1.72 S.W.) pierces the Alluvium and descends through 80ft. of drift before reaching solid rock. The latter junction is 67ft. below the present level of the Irwell, which here flows on solid rock about 140yds. south of the bore-hole. Here, then, it is obvious that the Pre-Glacial valley of the Irwell was at least 67ft. deeper than the present valley, and it may well be that such differences prevail all along the upper reaches of the Irwell system.

To sum up : The course of the Pre-Glacial valley of the Irwell, plastered by drift, can be recognised to the east and west of Thrutch Gorge, but to the north the valley is completely buried by thick Glacial deposits. We may safely conclude that the gorge was cut by the Post-Glacial diversion of the Irwell, due to the obstruction of its old course by Glacial drift.

In conclusion the authors would like to tender their grateful thanks to Mr. James Hargreaves of Bacup, whose personal knowledge of the district has been of invaluable help in the field.

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Photo by V. Dean.

THE THRUTCH GORGE, LOOKING EAST.

PRACTICAL GEOLOGY IN ANCIENT BRITAIN

Part I.—The Metals

By C. E. N. BROMEHEAD, B.A., F.G.S., F.R.G.S.

(Presidential Address, delivered 7th March, 1947)

[Received 7th March, 1947]

ONE of the foundations of Britain's greatness is geological—her mineral wealth, the adaptation of which to human uses constitutes practical geology. As soon as Britain appears on the stage of history, that is from the Roman Conquest, many mineral substances were fully exploited, in fact their known existence was one of the reasons for that conquest, as were the minerals of almost all the outlying regions of the Roman Empire ; but long before the written history of our island begins archaeology and pre-history can tell us much about the working of flint, mineral ores, ornamental stones, etc. It seems worthwhile to collect and classify, from the geological point of view, the widely scattered information on the subject.

On this occasion I must confine myself to the metals ; I hesitated whether to include flint here : it was the first substance, of a nature which enables examples to survive for our study, to be used for the production of weapons and tools and so is the direct predecessor of the metals.

On the other hand, the literature of flint mining is almost confined to a few obvious and readily accessible publications and it has been summarised in several recent books, of which one of the best costs one shilling. One of the few really geological points to emerge is the evidence of the Grimes Graves region that when an unusually satisfactory seam of flint had been found at outcrop it was later worked by bell-pits under considerable cover.

TIN

The first metal worked in Britain to be mentioned in history and tradition is tin, which, on account of its comparatively rare occurrence and great usefulness and its abundance in Cornwall, has been a mainstay of British mining until its approaching exhaustion. It is only natural, therefore, that the working of our tin in very ancient times became the subject of a myth to the effect that at least by 1000 B.C. the Phoenicians traded tin from Cornwall to Egypt and the near east. This myth has followed the normal course of evolution, comparable with that of Noah's flood. A period of gross expansion leads inevitably to total denial which, when the available evidence is soberly collected and examined, is succeeded by recognition of a substratum of truth. It is not for

geologists to follow the process in detail, but to take notice of the result. British tin did reach the Levant at any rate by 1000 B.C. Archaeological evidence gradually accumulates, showing that objects of eastern Mediterranean origin are found in southern Britain of that date or earlier, and tin is the obvious article of exchange.

There is plenty of evidence for the working of tin in Cornwall in very early times, well back in the Bronze Age. At Carnon in a tin-bearing stratum in the river deposits a horn pick was discovered. It was in two parts : the beam was pierced just above the burr, the tines removed and a dressed tine inserted and, presumably, fastened by a cord. A similar tool from Nointol, France, is dated to the early Bronze Age. The Carnon pick was accompanied by a human skull, a wooden shovel and horns ; these objects lay far below present sea-level and also below a layer of oyster shells *in situ*. In stream-works at Pentreven relics of human occupation were found 40ft. below the surface and also below a stratum yielding remains of an extinct whale, *Eschrichtius robustus*. Carey in his survey says that picks of holm (holly), box, or hartshorn were found daily among the refuse of old works in his time, 300 years ago. In nearly all the old tin streams blocks of stone with cup-like hollows, due to their use in pounding the larger lumps of ore to powder, have been found at varying depths. A good many bronze axes have also been found. That no actual tin-mines of Roman or earlier date are known need not surprise us, since the early works were all alluvial.

Another important find is the tin ingot from Falmouth harbour. It is 2½ft. long and now weighs 159½ lbs., but a small part has been removed for analysis. Its shape, as remarked by Sir Henry James, is admirably adapted for transport either at the bottom of a boat or by pack-horse : for the latter the weight, 160 lbs., is correct, one ingot being strapped on each side. In one corner it is stamped with a miniature representation of itself, presumably a trade-mark. There is nothing about this ingot to give an exact date, but the type is undoubtedly early. In the Manchester Museum there is a set of foundation deposits from a temple of Tausert, a queen of the XIXth Egyptian Dynasty at Thebes : it consists of miniature tools, etc., in sheet copper and includes an ingot very much like that from Falmouth, with which it has been compared by Flinders Petrie : the date is about 1200 B.C. A somewhat similar ingot, probably of copper, is shown in a fresco in the tomb of Rekhmara as part of a tribute from Cyprus ; this dates from about 1447 B.C. An ingot of this form has been found at Enkomi, Cyprus, with Mycenaean relics ; it weighs 81 lbs. and is stamped with a character in the ancient Cypriot script ; it is now in the British Museum. Similar ingots come from Sardinia and Crete. As early as 1500 B.C. separate ingots of tin and copper were used in Egypt for the manufacture of bronze : the tin may, perhaps, have been British even then : for Egyptian faience beads had already reached Britain, though not necessarily direct.

All the available evidence for tin working in Cornwall from the earliest times up to and including Roman has recently been collected by Hencken in the County Archaeology and recorded in map form.

My old master, Clement Reid, from an intimate knowledge of the geology of Cornwall, has discussed the steps by which the use of tin may have arisen. The first stage is the use of cold-hammered native metal, in this case copper. Native copper can be seen in veins near Mullion and a mass of 104 lbs. has been found in the mines: other occurrences are in the St. Just district and near Camborne. When the discovery that the metal is fusible was made it would soon be learnt that such conspicuous minerals as malachite and azurite, which accompanied the native metal, also yielded it. Once the smelting of ores began the Cornish miners would find that some lodes yielded red copper, the pure metal, others a tougher and therefore more valuable variety, bronze, and yet others, as at Cligga Head and St. Agnes, a brittle white metal, tin. The soft copper tools and brittle tin tools would be remelted and, by happy chance, the surprising discovery would be made that the mixture was hard bronze. Tin would now be identified with the large brilliant faceted crystals of tinstone at Cligga Head, St. Just and St. Michael's Mount.

Up to this stage the mines would be entirely in the lodes seen in the cliffs. The export trade was carried on by coasting vessels, for the deep, densely wooded and marshy valleys made land-carriage very difficult anywhere near the coast. The next stage was the discovery by men washing for gold on the open moors that with the gold occurred grains of heavy tin ore, like that of the lodes, but of better quality, more easy to obtain and always yielding tin without admixture of copper. For export to countries yielding the more abundant copper, tin alone was required. The reduction of weight would amount to 90 per cent., an important consideration as it would favour the introduction of land-carriage instead of a very dangerous voyage round the Lizard. The inland position of the first shallow stream-tin works on the open granite moors near the watershed would also render land-carriage more easy while the sea was less convenient of access. Copper lodes were now abandoned and alluvial washing alone undertaken as long as stream tin was obtainable in quantity close to the surface. This was the stage reached by the middle of the first century B.C. (I should put the date much earlier) when tin was exported, but copper was imported. Copper pyrite, which forms the inner part of the lodes, was probably a useless ore to the natives, who could only work oxides and carbonates. No doubt much of the tin obtained was used at home. Early Bronze Age weapons in Britain may have been imported, but by the Middle Bronze Age they are probably indigenous. A small whorl or bead of pure tin has been discovered at Glastonbury in the Iron Age lake-dwellings.

To learn something of the export trade in tin from Cornwall we must turn to literature. The earliest records are extracts from the lost writings of Pythias by the Greek historians, Strabo and Diodorus Siculus. We learn that about 325 B.C. Pythias sailed from Marseilles to Brittany, Cornwall, along the south coast of Britain, to the Baltic and back. Tin was then, apparently, shipped to the mouth of the Loire and taken thence either over land to Marseilles or more probably, as Hencken suggests, on by sea to the Garonne and through the Carcassonne Gate to Narbonne. There is good evidence that this trade route was in existence by 450 B.C. and continued till the port of Corbilo at the mouth of the Loire was destroyed by Julius Caesar in 56 B.C. After that we hear no more of British tin.

If we turn to the details of the various early writings on the subject we find ourselves involved in two difficult questions which have been discussed by classical scholars, historians, archaeologists, geologists and all sorts of people. We learn that the tin came from the Cassiterides or Tin Islands, a group of 10 or 14 off the coast of, or near to, either Spain or Britain. After being cast into ingots it was conveyed to the island of Ictis, which, at low tide, was accessible by a causeway from the mainland. There are no plausible candidates for identification with the Cassiterides; for Ictis there are half a dozen rival claimants, of which that now generally accepted is Michael's Mount, which still answers to that part of the description which I have mentioned. A number of arguments converge in its support. It contains veins of tinstone and there are abundant remains of ancient scoriae, showing that it was a smelting centre. Again there is a close geographical resemblance between it and the ports of Tyre and Sidon. The Phoenicians, with whom, as we shall see, the origins of the tin trade and the first knowledge of Britain have always been associated by tradition, seem to have had a great liking for peninsula sites resembling their home ports; practically all their colonies, notably Cadiz, are of this type. Thucydides (vii, 2) tells us that the Phoenicians had settlements all round the coasts of Sicily. They secured the capes of the sea and the small adjacent isles for the purpose of trafficking with the natives. Moreover, a Sicilian bronze axe has been recorded from near Hengistbury Head by C. F. C. Hawkes. I do not think there is any solution to the question of the Cassiterides; Rickard's conclusion is that "not enough note has been taken of Strabo's remark that the Phoenicians tried to mislead their contemporaries as to the whereabouts of the tin mines," and Haverfield's is practically the same. The Cassiterides may well have been a geographical Mrs. Harris.

The tradition that the Cornish tin trade was begun by the Phoenicians goes back a long way and has much in its favour. They were certainly the earliest long distance navigators of the

Mediterranean and were the first to sail through the Straits of Gibraltar ; they founded Cadiz about 1100 B.C. Ezekiel, writing about 600 B.C., says that the markets of Tyre supplied silver, iron, tin and lead from Tharshish, which was certainly Cadiz and its neighbourhood. They may well have known of the existence of Britain by 1000 B.C., though the earliest statement we have is Pliny's that Himilco, a Phoenician, went a voyage to Britain about 500 B.C. It was the tradition of this early Phoenician trade that inspired the expedition of Pythias from the Greek colony of Marseilles about 330 B.C., and two hundred years later the visit of Posidonius, who found the export of tin to the continent flourishing and the miners civilised, hospitable and expert. It is possible that for "Phoenician" it would be more accurate to say "Phrygian," amending the reading of a personal name in one of the texts ; all of these are given with commentary by Rice Holmes ("Ancient Britain and the Invasions of Julius Caesar," 1907). For geologists the point is unimportant compared with that of the date ; and the allusion to tin trade at Tyre in Ezekiel is still significant.

Moreover, precise archaeology is constantly tending to confirm the tradition against the scepticism of a few years back. At Gaza in Palestine Flinders Petrie has found ornaments of gold, which he says are undoubtedly of Irish origin and manufacture, dating back to about 1200 B.C. ; though apparently based on stylistic grounds only, the statement has been repeated this year by Sir Leonard Woolley. Calais beads from Brittany are known almost as far back as that from numerous localities round the eastern Mediterranean. An Irish halberd of the earliest Bronze Age has been found in the bed of the Loire, an indication of the probable route for this trade ; and in the opposite direction, though much later, various Mediterranean coins and four Greek lekythoi of the fifth century B.C. have been found in Cornwall.

There is an undoubted connection between Cornwall and Brittany and thence through Southern France to Portugal and Spain from very early times. A polished jadeite axe from Falmouth seems to be of Breton origin and several bi-conical pots have been found of a type peculiar to Brittany. It would be outside my province to go into greater detail, but, with the proved connection, we may suggest that Brittany, also a tin-producing area, was throughout the Bronze Age a stage in the route by which Irish gold and Cornish tin reached the Mediterranean. The early merchants avoided long sea voyages whenever they could and even cut across land to escape rounding stormy headlands. The Bronze Age route from Egypt to Greece did not round the eastern end of Crete, but crossed the island by land. Similarly, I should expect the Cornish tin to be brought along our south coast to near the Isle of Wight, thence by the short passage past the Channel Islands to Brittany and then by land to Vannes and Corbilo, avoiding the

dangers of Ushant. In the north of Brittany there are several harbours of the Phoenician type ; Mont St. Michel closely resembles St. Michael's Mount, with which it has many connections. Even in medieval times the two were sometimes confused and a legend, belonging to the French site, but wrongly transferred to the British, has been used as an argument against the identification of the latter with Ictis. The present route from England to Brittany is Southampton to St. Malo. Close to the latter is St. Servan, a port of Phoenician type, whose known history goes back to early Roman times. I suggest that this route was open at any rate by 1000 B.C. When the inquisitive Greeks tried to learn whence the tin came the accounts they got were garbled—both innocently by the ignorant and intentionally by those who had a valuable secret to keep. We are even told by Strabo, after his account of the Cassiterides, that on one occasion a Phoenician ship engaged in the tin trade was followed by a Roman vessel. Rather than betray the secret the Phoenician captain deliberately led the boat to destruction. He escaped with his life and the merchants showed their appreciation by giving him the value of his lost ship and its cargo. We need not be surprised that the surviving statements about Ictis and the Cassiterides are irreconcilable with the facts. Professor Warmington has shown that the sources of cinnamon, silk and other products of the Far East were kept secret in a similar way. Intermediate markets were often said to be sources. Even tin itself was stated in the second century B.C. to come from two completely unmineralised islands in the Adriatic.

We have seen that the export of tin from Cornwall practically ceased about 55 B.C. After the conquest the Romans seem to have almost neglected it for many years. At Tregear near Bodmin a few mining tools have been found, accompanied by coins and pottery dating from the middle of the first to the middle of the second century, but the settlement was small and probably native. Other relics occur in Penwith, but the trade was short-lived. A possible indication of this early Roman working was found at Lyons—a hoard of 700 tin denarii of Septimius Severus (193-211). His visit to Britain may have suggested the use of tin to eke out the scanty silver coinage, as British coins of tin, probably dating from about 100 to 50 B.C., are known ; many have been found in the Channel Islands. Severus's experiment was not unnaturally dropped : one of these coins is also recorded from Cordova, Spain.

About the year 250 tin working was revived under imperial control. From Carnanton we have an inscribed and stamped ingot of tin now in the Truro Museum and objects of tin and pewter become common ; a tin jug from Carhayes contained about 2,500 third brass coins of A.D. 260-273. Roman stream-works have been recorded by C. C. James from near Wheal Vor. A mask of nearly pure tin was found at Bath and seven pewter vessels in a well 38ft.

deep at a Roman villa at Brislington near Bristol. An interesting hoard of tin and pewter of about A.D. 350 was found at Appleshaw, Hants; a dish now $7\frac{3}{4}$, originally about 9 inches, long is 99.18 per cent. tin. Nor are objects of tin confined to the south: a cup from High Rochester, Northumberland, described by Richmond and Smythe, consisted of tin 95.6, lead 4.5 per cent. A lump of tin was marked with the Christian monogram, which also appears on others found in the Thames and dateable to 360 or 380; two are now in the York Museum. Ingots of silver from London were probably for the mint and not necessarily British.

Actual remains of mining are scarce and seldom dateable; oaken shovels in stream-works may be of almost any date from prehistoric to medieval. A tin smelting furnace at Trerife has been claimed as Roman, but it and a block of tin from it bearing a merchant's mark are more probably medieval.

COPPER

If bronze was being made in Britain as early as the Middle Bronze Age, it follows that copper was being worked. Apart from the rare occurrences of the native metal, definite mining, in early times by open-cast, is necessary. We are fortunate in having distinct traces of this activity in Anglesea and various places in Wales, at Alderley Edge, Llanymynech (Salop) and Coniston. The workings at Alderley Edge are probably the oldest and also the best known, but working seems to have continued throughout Roman times and was resumed from the 18th century, so that much of the evidence has been disturbed. The early remains are all of Pre-Roman character; the natives continued to employ their primitive methods, presumably paying tribute, during the Roman occupation, in contrast with the lead mines which were imperial property and worked on the highly developed system evolved in Spain.

The rock is soft Lower Keuper Sandstone impregnated with copper carbonate. It was broken up with stone hammers, of which very many examples have been found; there is no trace of iron tools. The hammers are made from drift boulders, mostly a hard brownish-green mica schist, but also greenstone, hornblende granite, Carboniferous Limestone, etc. Of one collection of 29 examples, 21 have a single central groove for hafting, seven a central and a transverse, one a central and a lateral groove. In one case the central groove has a slight elevation along the middle line, showing that a double twist of withy was used. The weights vary from 1 lb. to 15, but 4 or 5 lbs. is usual. A very roughly used oaken shovel has been found with stone hammers and axes in an open-cast 12 to 16ft. deep. No attempt was made to drive galleries; in one area a number of circular pits was dug in a bed very rich in

blue nodules of copper silicate. The least disturbed of the open-cast trenches is at Brindlow, where the hammers found were encrusted with patches of malachite.

Smelting was done on the spot, vitrified copper scorise, charcoal and laminated pieces of copper being common. In the neighbourhood a neolithic flint chipping floor, numerous Bronze Age relics and a few Roman coins have been found.

In Anglesea and Holyhead much copper was mined by primitive means, and a Middle Bronze Age palstave-mould has been found ; but most of the objects precisely dateable are Roman : no doubt pre-existing native works were continued under Roman rule. A number of cakes of copper have been found ; they are circular, with a diameter of 11 to 13in., a depth of 2 to 2½in., and weight 30 to 50 lbs. They have been formed by pouring the molten metal into a shallow tray, and a comparatively smooth band which is always found on the upper surface immediately within the perimeter is due to the more rapid cooling of the metal at the point of contact with the cold tray. The central part shows a marked rising, due to the evolution of sulphurous acid, showing that sulphide ores were smelted. The metal must have been ladled from the furnace, not tapped. One came from Amlwch and weighs 42 lbs. and is stamped IVLS ; another is stamped SOCIO ROMAE.

The country rock is composed of Silurian and Ordovician shales with a thick sill of felsite near the junction. There are no true lodes, the parts worked being zones of maximum chalcopiritisation. The ores are copper-pyrites and the pure copper sulphide known as copper glance, chalcocite or Redruthite, an ore which may also have been worked in Cornwall in early times. It was dug out of shallow pits with stone hammers and picks, pounded with hammers and stone balls in mortars, several of which have been found, and finally smelted on the spot ; a bellows nozzle of baked clay has been recorded.

Copper was worked near Llandudno in Roman times ; an open-cast on Great Orme's Head yielded a coin of Aurelian, and many coins of late third and fourth century date are recorded in association with spoil heaps, etc. The ore here is a carbonate. At the western end of Montgomery, in the park at Machynlleth, a Roman mine was reopened in 1856 and produced copper and lead ; according to Hunt the tools found in the old workings were certainly Roman. At Llanymynech on the borders of Shropshire similar ore has been worked ; the copper salts here occur in Carboniferous Limestone and have been concentrated by percolating water at a marly band. The Roman works are a large number of cone-shaped pits and a great open-cast with a series of galleries opening into chambers—Pennant speaks of a "great artificial cave." The date is given by coins of Antoninus and Faustina. Some pits in line are considered by Mr. Wedd to be excavated swallow-holes ; one

recalls similar works at the present day for barytes in Derbyshire. The cavern at Ogof on Llanymynech Hill is the entrance to a Roman adit.

At Coniston, about 1 mile W.N.W. of the church, some of the copper lodes are said to have been worked in Roman times and possibly earlier : the ore is attractive to miners using primitive methods, consisting largely of malachite in a soft matrix.

I am not aware that any other workings for copper are known to be Roman or earlier, but traces of copper and tin smelting, apparently belonging to the Early Iron Age, have recently been found at St. Columb Porth near Newquay. A few inferences may, however, be drawn from finds of worked metal. The Everthorpe hoard, now¹ reassembled at Hull, includes crucibles containing masses of practically pure copper, whereas the implements are of bronze—in one case containing 10.5 per cent. tin and 22.4 per cent. lead. During the late Bronze Age all three metals were therefore known and prepared separately, being subsequently alloyed for use. A celt from Birtley dating from the entry of Bronze Age folk into the Wear Valley is rich in tin ; both it and the copper must have been remarkably pure.

The Romans, or natives under Roman rule, must have mined copper in south-west Scotland and in Cornwall ; from the first comes a cake of copper agreeing in appearance and composition with the Welsh cakes ; from the latter a vessel of pure copper found in 1825 in the marshes at Marazion containing some thousands of third brass coins of round about A.D. 260.

Copper was mainly used, not in its pure state, but alloyed with tin to form bronze ; it was also alloyed with lead, zinc, silver and antimony. The early use of a copper-lead alloy is noticed above ; it was continued by the Romans for cast bronzes. The subject of Roman copper alloys has been studied by Dr. J. A. Smythe, who notes percentages up to 14 of lead from the Roman Wall, and proves that it was a deliberate addition to facilitate casting, since bronzes free from lead, but containing from 2.9 to 10 per cent. tin, occur contemporaneously. Although metallic zinc is usually considered to have been unknown till the time of Paracelsus, about A.D. 1500, the zinc-copper alloy, brass, was familiar to the Romans, who produced it by smelting calamine with copper ores. The earliest brass coins date from 20 B.C. and contain 17.3 per cent. zinc. There is some slight evidence that they mined calamine in Wales and Shropshire. The specimens of brass from the Wall examined by Dr. Smythe show various percentages, but several are very close to copper 87-zinc 13, the modern gilding metal. He also notes objects of copper-silver which fall into two groups of 80-20 and 50-50 parts.

¹ Probably destroyed by bombing.

Interesting metallurgical remains have been found at Hengistbury Head and described by Gowland : they include cupellation furnaces of bone-ash and sundry blocks of metal alloys. A cake of copper weighing about $5\frac{1}{2}$ lbs contained 98.5 per cent. of that metal and no tin ; more interesting is a mass, weighing $19\frac{1}{2}$ lbs., consisting of 50.45 per cent. copper, 46.43 silver, 1.2 gold and again no tin. Gowland concludes : "It is extremely probable that the source of the copper-silver block was the mineral district of Callington, where native silver and other silver ores proper are associated with copper ores, and that the alloy is the result of the cupellation of argentiferous copper or argentiferous cupriferous lead obtained from that district. It was in my opinion intended to be treated further by cupellation for the extraction of the silver." These works were apparently carried on by native Britons before and during a large part of the Roman occupation.

LEAD

Lead was by far the most important mineral product of Roman Britain and had undoubtedly been worked very much earlier. The Everthorpe hoard has already been mentioned ; the presence of over 22 per cent. of lead in the bronze here and in Weardale suggests that local lead was added to save copper brought from a distance ; the leaden socketed axe from Seamer, probably a model for making clay moulds, as described by Sheppard, strengthens the supposition that the working of lead in the Yorkshire Dales goes back to the Bronze Age.

In Somerset the lead-mining debris of the Mendips has yielded several fibulae of pre-Roman type and some British coins ; the metal was used during the Iron Age at Glastonbury for net-sinkers and whorls. It is quite probable that all the Roman lead-working areas, except perhaps those in Wales, were active before the conquest.

Of Roman work the earliest evidence is a Mendip pig dated A.D. 49. The chief centre in the Mendips was at Charterhouse near Blagdon. Traces of buildings and of lead smelting were first noticed about 1819 or 1820. In 1867 to 1876 attempts were made to resume mining and in particular to re-smelt the vast heaps of imperfectly treated ore. Many Roman remains were discovered, sufficient to indicate an active mining industry and a large mining population, but unfortunately there was no systematic archaeology. Some mining implements of wood and iron, undoubtedly Roman, are in the Taunton Museum ; the most interesting find is a miner's lamp of lead of a type familiar throughout classical times from the fifth century B.C. onwards ; two other lead vessels are imperfect but by comparison almost certainly lamps. It is strange that Haverfield failed to recognise the almost complete one and in his excellent account of Roman Somerset in the V.C.H. figures it as a "crucible with lead handle."

The ore is galena, with a little cerusite; it occurs in veins in the Carboniferous Limestone, mainly east and west, with minor cross-courses at right angles. Probably most of the ancient works were open-cast, no certain evidence of Roman adits or shafts other than the miners' lamps just mentioned being known, though it has been claimed that a part of Wookey Hole is a Roman lead mine, an inscribed plate of lead having been found there. We may compare Pliny's statement that the abundant lead of Britain was on the surface and required no true mining.

Around Charterhouse an area four miles wide from Blackdown to Priddy was worked. The well-watered valley of Blackdown was used for washing and is choked with debris; the buildings and furnaces were on the slopes; a layer of scoriae and charcoal two feet thick is mentioned. An oaken miner's spade, with more claim to be Roman than many similar ones from various districts, is cut from a single block, 21 in. long; the handle is square, the blade 11 by 8 in. with squared sides. Many crucibles, small leaden objects and an unmoulded mass of 78 lbs. of lead have been found, but the most important evidence is the pigs, of which 12 with inscriptions can safely be connected with the Mendips. A large amount of lead was used at Bath, where the great bath was lined with sheets 8 ft. by 10, weighing 30 lbs. to the square foot, burnt together at the edges without solder. The metal was also exported: Mendip pigs have been recognised at Bristol, which would be an obvious port, at Clausentum near Southampton and at Valéry-sur-Somme in France, the last probably lost on its way to Rome. The lead is poor in silver, mostly about 3 oz. to the ton; but one pig from Blagdon gave 8 oz., 6.6 dwt.; this one is not marked EX ARG; otherwise there is no difference between those thus marked and those not. A fragment from a Welsh pig, found at Pentre, showed 9.16 oz. of silver, but a piece of pipe from the same site only 0.11, showing that extraction was very good.

The Roman activity can be proved from A.D. 49 to about 165; then came a pause followed by revival under Carausius and the Constantines. The mines appear to have remained imperial property all the time.

A certain amount of lead occurs at Bere Alston and Coombe Martin: ancient scoriae have been found, but their attribution to Roman times is doubtful.

In Shropshire lead occurs in grits, ashes and shales of Ordovician age around Snailbeach and Shelve, west of the Stiperstones. In the soft shales and in the quartzites of the Stiperstones the veins and fissures in which the lead is found tend to pinch out and become impoverished. The Romans worked a great many of the veins by open-casts 20 to 50 ft. deep and mined by shafts and galleries to a depth of 300 ft. The vein on which the deepest workings occur is still called the Roman vein and two of the principal mines of the

district are known as Roman Gravels and East Roman Gravels respectively. Three inscribed pigs have been found, all of Hadrian's reign, A.D. 117 to 138. These were accompanied by coins and pottery, oak spades and candles with hempen wicks. Some of the spades have very short handles and a hole in the centre of the blade, perhaps for the insertion of a lever-handle; they are now half an inch thick and are roughly cloven with a wedge-shaped tool, not smoothed. But there may easily have been some intermixture in the galleries with later remains, and similar spades at Great Hucklow are dateable to the early 17th century. Shropshire pigs have been found in Germany and France.

In Wales traces of Roman lead-mining have been found in Flint, Denbigh, Carnarvonshire, Montgomery and Cardigan. The Flint-Denbigh area was probably occupied by a tribe called the Decangli by Tacitus; four pigs of lead stamped with a similar name have been found in Cheshire and Staffordshire, belonging to the reigns of Vespasian and Domitian. A coin of Gordian III is said to have been found on the old floor of a lead mine at Talagoch near Dyserth. No doubt much of the metal was used locally at Chester, where inscribed lead pipes dated A.D. 79 have been found. Near Abergele are what have been described as "some of the most perfect Roman mines in the kingdom. A hill known as Castell Cawr has been completely cut across by a deep trench called the Ffos-y-Bleiddard or wolves fosse. In driving a level towards the close of the 18th century miners discovered that the Romans had been deep in the bowels of the earth; they had followed the vein where it was large enough to admit a man and, where it opened into a large chamber, they had cleared it quite away. Some curious hammers and other tools were found and the golden hilt of a Roman sword." Unfortunately the mine thus described has not been competently examined in recent times, though the entrance, close to a house known as Tan-y-goppa, is easily reached. There seems no reason to doubt that the finds were Roman, though we may well question the description of the sword-hilt as golden. Old shafts, trenches and other evidences of mining are scattered over a wide area, but few can be definitely dated. The best-known mines are the Minera near Ruabon and at Talargoch, where some of the workings are undoubtedly Roman. On two sites near Flint there is abundant evidence of furnaces for lead smelting associated with Roman remains and it is possible that Flint itself may have served as a small port for exporting the metal. Two miles west of Flint is Halkyn Mountain, where some of the open-casts on the "Long Rake vein" are attributed to the Romans. A stamped pipe found and preserved in Chester is dated A.D. 79.

Further south, at Llanymynech Hill, near Oswestry, the Roman mines already mentioned as working carbonate of copper also produced lead and orange-coloured ochre. Less substantial evidence

is afforded by the alleged discovery of a small bronze vessel with remains believed to be Roman at the Goginan lead mines near Aberystwyth ; an adit at 20 to 30 fathoms is known as the Roman level, as it is cut entirely with chisels. At Cwmysthwith Mine, Cardiganshire, oval-shaped dressing-stones from an open-cast are probably Roman. In South Wales Roman coins are said to have been found in a lead working at Cefn Pwllddu near Ruperra, not far from Monmouth.

It is clear, therefore, that lead ores were worked by the Romans in many parts of Wales ; they probably also made use of the zinc ore, calamine, which frequently accompanies it, for making brass. It is unlikely that lead was worked in earlier times as the Welsh name for the metal is Plum, obviously of Latin derivation.

One well-known mine has not been mentioned, that of Daren in Cardiganshire, a little south of Aberdovey. It was called Roman by Pettus in his book *Fodinae Regales*, published in 1670 ; but there is no evidence for the attribution, other than the fact that it must have been regarded at that date as very old. His illustration is attractive ; it shows the old Roman fort (A1, 2) and the Roman Trench through and across the hill (B).

In Roman times Derbyshire probably had the largest output of any district, the maximum being in the third and fourth centuries. Eight pigs have been found in and four others are referable to the county. The earliest is dated A.D. 81, the same as Yorkshire, as compared with 49 for Mendip and 74 for North Wales. In one respect this district is unique. The mines of Lutudae, between Wirksworth and Castleton, were not under direct imperial control, but owned by or leased to individual owners, such as P. Rubius Abasiantus and C. Julius Protus. One pig has been found still in the mould and one from Matlock Moor was associated with a smelting hearth. Many similar hearths are known ; but the same type, crudely built of stones with an opening to the prevailing wind, but no artificial blast, was in use till 1681 and exactly dateable instances are rare. In the Castleton district the Blue John and the Treak Cliff mines are doubtfully attributed in part to the Roman period. Coins have, however, been found in the Longstone Edge Mine.

A pig found many years ago at Brough-on-Humber and now in the Hull Museum (unless destroyed in the war) probably came from Derbyshire, not from the Yorkshire Dales. In 1940 five more pigs were found at Brough, accompanied by pottery of the second and third centuries A.D. Four of them carried inscriptions including the words LUT. BRIT. EX ARG. The weights varied between 190 and 196 lbs. One was found to consist of 99.9 per cent. lead. The fifth pig was in a rough clay mould, incomplete, with no inscription, weighed 80 lbs. and showed the layers from the filling unusually clearly ; smelting or re-smelting of the metal

must have been done on the spot. Presumably this Derbyshire lead was to be exported from the Humber; the late T. Sheppard said that he saw a Derbyshire lead pig in Naples. It is interesting to note that Pliny tells us that a quota was imposed on the export of lead from Britain. The Humber shipping trade must, therefore, have suffered from the restriction of output from mines in Derbyshire and Yorkshire 1,800 years ago as well as in our own days.

In Yorkshire the strong presumption that lead was worked before Roman times has already been mentioned. The first discovered proof of Roman working is also the earliest dated. The two pigs found in 1735 at Hayshaw Bank bore the description IMP CAES DOMITIANO AUG COS VII, giving A.D. 81 for the working of the Greenhow Mines: other pigs from this district have the word BRIG from the local tribe of Brigantes. At the Hurst mines in Swaledale Roman workings were found similar to those in South Wales and Shropshire; a pig found has the name of Hadrian (A.D. 117-138). Another curious discovery is recorded between Grassington and Pateley, of a half-size pig (85 lbs.) with the name of Trajan and the date A.D. 98, but the pig itself is missing. It has been pointed out that the weight of a Roman pig, about 170 lbs., together with its subdivisions, remained the standard up to the present day. In addition to the adit at Hurst Mine there are others of Roman date at the Jackass Mine and the Sam Own Panty level, Greenhow; they have been driven 300 yards through grit to limestone and have a uniform section of 3ft. by 2. Dr. Raistrick, who has recently summarised all that is known of the subject, points out that there is good evidence that the Romans used the method known as "hushing," which has survived to the present day. The hillsides, consisting of Yoredale Shales and Grits, have weathered in steps, but the treads, the upper surfaces of the grits, are usually covered by thick debris. Where the weathered rock suggests the near presence of a lead vein a hush is made: that is, a reservoir is constructed higher up the hillside with a turf embankment. When the pond is full the turf bank is cut and the rush of water scours a clean section of solid rock to the bottom of the valley, thus revealing the crops of the veins. Crop-workings with Roman pottery, etc., among the debris have been noted near Grassington.

Further north, in Allendale and on Alston Moor lead was almost certainly worked by the Romans: Phillips pointed out that the Roman Wall encloses and bounds the rich lead districts, occurrences north of it being very small. Much lead was used for clamping stones, notably in the Roman bridge at Cilurnum (Chollerford). Though actual workings cannot be recognised, traces of Roman occupation occur wherever lead has been found, however remote the situation.

On Walsingham Moor, County Durham, the best authenticated

Roman lead smelting furnace was found in 1920. A bronze lead-pouring ladle was accidentally discovered and is now in the Museum at York ; it holds $2\frac{1}{2}$ pints. Excavations were made at the site and "lead, slag, charcoal and wedge-shaped fire-resisting stones were found, showing that there had been a lead furnace erected at the edge of the mountain and a flue had been formed to catch the prevailing wind and act as a blast to the furnace." About one mile away is a Roman penal settlement, erected between A.D. 100 and 117, described by Alderman Wooler, in which the convicts who worked the lead were housed. Such ladles were evidently the normal means of pouring the molten metal into the pig moulds. Gowland pointed out that in every pig he examined the metal was stratified, showing that only a small quantity was poured into the mould at a time, each layer partly solidifying before the next was added.

IRON

The working of iron in Britain began at least as early as the La Tene I period : iron slag, dateable by associated pottery, has been found at several sites, notably at Bigberry Camp in Kent. At All Cannings (Wilts) the settlement lasted from late Hallstatt to early La Tene times, say 500 to 300 B.C. The iron ore of the Lower Greensand of Seend nearby was worked. The slags indicate smelting with charcoal at a temperature of about 1,100 C. to form a bloom of iron from which hooks, awls, tanged blades, a curved blade that may have been a sickle, shears, swan-necked and other pins, etc., were made. Saxonbury Camp was occupied by iron smelters whose pottery is dated from 50 B.C. to A.D. 50. There is much iron-cinder of Roman date around Devizes.

Caesar found the Britons using iron, and at certain of the Roman bloomery sites in the Weald the lowest layers of slag and scoriae have yielded a few pre-Roman objects. Of actual mining before the Romans we have no trace. The Romans worked iron on a small scale at numerous localities, e.g. all along the Wall, but large outputs were obtained from two areas, the Weald and the Forest of Dean.

In the Weald the chief source of ironstone is the Wadhurst Clay, the middle division of the Hastings Beds, in which it is exceedingly abundant, so much so that to waste a large proportion of the iron was of no consequence if the method of treatment was otherwise satisfactory. Two methods have prevailed in the Weald, the Bloomery and the Blast Furnace. In the first a mound is made of alternate layers of ore and charcoal and then covered with clay : the floor or hearth of stone or resistant material has a hollow in the centre to receive the iron. A hole is left for the escape of some of the cinder and another for the bellows. A continuous draught from simple bellows is necessary for iron : the prevailing

wind is not sufficient as it was for lead furnaces on the Derbyshire hills. The result is a lump of malleable iron, which can be hammered to free it from cinder, giving a bloom of wrought iron. In the bloomery the iron seldom becomes really molten. Bloomeries are usually near a small stream, either for drinking or for cooling the tools in the subsequent treatment. The waste material is cinder containing 30 to 60 per cent. of ferrous oxide.

The blast furnace is a permanent structure of some height, fed at the open top, from which fluid metal is tapped from time to time at the base. It requires water or other power for the blast, and also for the hammer by which the resultant cast iron sow and pigs are converted to bar iron. The waste is a glassy slag containing about 1 per cent. iron. This process was introduced into the Weald in Tudor times.

All the old Wealden iron-works have long been overgrown. A bloomery site can be distinguished from that of a blast furnace by the nature of the heaps of waste, cinder or slag. Straker has carefully distinguished several types according to date by general appearance, microscopic work and chemical analysis. A furnace site will show close at hand the artificial dam for water to work the blast and hammer, usually called a hammer-pond.

The surviving heaps of debris, where this has not been removed for road-metal before competent observation, often reveal stray objects which serve to date the works. At Ridge Hill, south of East Grinstead, a mound of cinder showed a succession of circular hearths, $8\frac{1}{2}$ to 9ft. diameter, each built on the top of the previous pile. Many layers contained Roman pottery; others below were undoubtedly pre-Roman. At Bardown, west of Ticehurst, the lowest ash-beds contained pottery of the La Tene II and III periods, 300 to 150 B.C., succeeded by Roman: there are many pre-Roman iron-works in Ashdown Forest. Footlands, between Battle and Robertsbridge, was an important Roman iron-works; remains found show occupation from A.D. 50 to 400. At Beaufort, five miles north of Hastings, a Roman iron statuette was found, to which I allude later. In all, nine bloomeries are sufficiently well authenticated to be marked on the Ordnance Survey Map of Roman Britain; several others are practically certain from the character of the cinder, but have not yielded dateable objects. Many bloomeries, both Roman and pre-Roman, must have disappeared through the use of the cinder for road metal. A Roman road has been traced from near Lewes through Ashdown Forest to Edenbridge and on to London, passing near several known Roman bloomeries. This road would serve to carry the iron both to London and to the coast for export. For a large proportion of the distance the road surface was made of iron-cinder: no doubt many pre-Roman works were obliterated to provide the metalling, just as some modern slag heaps disappear for the same purpose: Straker and Margary estimate that on this road alone 35,000 tons of slag was used.

There were never any real mines ; the ore was dug out of shallow pits, mostly in Wadhurst Clay, which were apparently used only for a single season.

In and around the Forest of Dean were a great many Roman iron-works, including in some cases extensive mines. At Coleford a large pit 20 to 30 yards in diameter was sunk and the vein followed in galleries ; many Roman coins were found in them. At Great Doward there is a large cave-like aperture with galleries running from it into the hill in several directions. It is now called King Arthur's Hall, but is undoubtedly Roman. At Lydney there is a shaft sloping down at 20 degrees, 1ft. 6in. to 2ft. wide, with the marks of pointed picks fresh on the walls. The entrance was blocked by a Romano-British hut dating from towards the end of the third century, by which time this mine must have been abandoned. Immense areas in Monmouth and southern Hereford are covered with layers of scoriae, sometimes up to 20ft. thick, many of which have yielded Roman coins, though others are medieval : the name Cinderford is derived from these.

The centre of the Roman industry was the town of Ariconium, situated three miles east of Ross-on-Wye, where remains of several forges have been identified. Coins indicate that during the first century the population was British natives looked after by a small military post. An era of intensive work was from A.D. 260 to 300 after which remains became very rare, possibly from exhaustion of easily reached ore. Another important site was Blastium, on which part of Monmouth is now built. Several Roman roads in this district have been metalled with iron-slag.

The bloomeries near the mines used charcoal, but not the local coal ; they produced wrought iron blooms, which would be sent for forging by smiths all over the country ; no doubt the Forest of Dean supplied the great military forge at Bath, where there was a "college of smiths." Actual lumps of iron, probably from the forest, are preserved at the Roman villa at Chedworth in the Cotswolds, which was later a fulling works. The largest weighs 484 lbs. and is probably an anvil composed of several blooms, as is that from Corbridge mentioned below ; another, which has been largely used in the smithy for making the varied small iron objects found on the site, is now only 256 lbs.

I am not aware of any actual remains in the Forest of pre-Roman iron-works. That the ores were used as early as Early Iron Age B (say 300-250 B.C.) seems certain. Sir Cyril Fox has shown that of the well-known British iron currency-bars some 85 per cent. (about 850) have been found within a radius of 40 miles of the Forest of Dean.

Further west, in Wales, coins of Antoninus Pius and pieces of Samian ware were found in or beneath a layer of scoriae taken to neighbouring iron-works for resmelting from Bolston Gaer,

Glamorgan, in 1752. Such resmelting has been frequent, as the Roman scoriae or cinders contain a large amount of iron. As in Sussex iron-cinder was used for road metal, the two main streets of the Roman fort at Cardiff being thickly paved with it. Slag used for the same purpose at Ely, not far from Cardiff, contains a good percentage of manganese, which would produce a hard iron, but as the ore has not been identified, it is not yet possible to say whether manganese was naturally present or deliberately added. In North Wales an open-cast in the haematite 30 yards east of the nickel-cobalt mine of Moel Hiradderg near Abergele contained a Roman sword and helmet.

The Northamptonshire ore was also worked, and at Colsterworth, south of Grantham, has been found a very fine iron-furnace of advanced type, but dateable by coins and pottery to between A.D. 75 and 150. It was built of well-puddled clay 3 to 4ins. thick; 3ft. 6in. long by 2ft. wide; depth at the charging end 18in., at the discharging 23in., due to the slope of the floor towards a dished hearth where a bloom could be worked before withdrawal for forging. In the sides are two large openings for blast pipes and in the top a number of vents which, when found, were carefully closed by fragments of pottery. It has been suggested that when the day's work was finished the furnace was charged with charcoal and the bloom returned to it; no blast would be used, but the vents covered. The fuel would smoulder all night at a red heat, and the iron would be partly carbonised to steel. Microscopic examination of the piece of iron found near the furnace agrees with this suggestion. Members of the Geological Survey who have recently made an intensive study of the Northamptonshire Iron-field have drawn attention to the fact that many traces of ancient iron working are found well to the east of the outcrop of the ore, but on that of fire-clays in the Upper Estuarine Series; a good instance is that of Newell Wood near Pickworth, fully five miles from the ironstone crop. A similar distribution of Roman iron-works has been noticed by Prof. O. Davies in the Jura.

At the Roman Camp of Marigdunum, on the Fossey east of Nottingham, a series of rectangular smelting pits has been described by Felix Oswald; they were lined with clay baked red; lumps of slag or cinder contained 40 per cent. iron; the ore came from the Belvoir Ridge and Lias limestone from Cropwell Bishop a few miles along the Fosse was used as a flux.

In Lincolnshire the Romans used the iron-ores of Frodingham and of Claxby. They worked the superficial weathered parts, where not obscured by blown sand. At the former locality scoriae and remains of smelting hearths accompanied by Roman remains have been found from Bogmoor near Scunthorpe as far south as Sawby. At Thealby, four miles north of Scunthorpe, many Roman ore pits have been found; they were very shallow, the largest

not more than 6ft. deep. Besides the Liassic ore Dr. Vernon Wilson tells me that the Romans used bog iron-ore. Cinder heaps are common all over the district.

In Yorkshire the Low Moor ironstone was undoubtedly worked in Roman times, but no mines have been recognised. There are heaps of ancient cinder in and around the Spen Valley ; at Brierley these yielded coins of Diocletian, Carausius, Constantius and Constantine, but nothing later. The industry must have ended then and the number of coin-hoards found suggests unsettled conditions. Roman coins have also been found in iron-cinder at Bradfield near Sheffield. It is doubtful whether the Romans used the Cleveland ironstone ; bell pits for the ore near Arncliffe in Eskdale and the Killing Pits south of Goathland have been attributed to them, but may not go further back than monastic times.

Several of the Roman iron furnaces have been excavated by competent archaeologists, and May's descriptions of those at Warrington and at Tiddington near Stratford-on-Avon have solved an old question by proving conclusively that the Romans could and occasionally did make cast iron. The furnace at Warrington was a permanent structure in which both haematite and clay-band ironstone were smelted : the ores were mixed, giving a more fusible mass and better yield than either used separately. Both cannel and ordinary coal appear to have been used as well as charcoal. The process was probably continuous, the metal being ladelled from a basin at the end of the trough of the furnace. A block of cast iron was found ; also a refining furnace in which it was reheated with charcoal to make malleable iron. Analyses and microscopic examination confirm all these particulars. The furnaces and hearth were made of soft boulder clay which, when baked, has been sufficiently durable to preserve every detail. Many manufactured articles were found, including nails, rivets, knives, etc., and the iron tube of a bellows-nozzle.

At Tiddington a complete industrial settlement has been unearthed : it comprises a tile-kiln with its adjuncts, water cistern, washing tank or slurry hole, drying floor with fire-hole and flues, ore-roasting and smelting furnaces for iron, lead smelting and de-silverising cupels and a number of ovens with fire-hole and cupola. It seems to have lasted from early in the Roman occupation down to about A.D. 530. The specimens of iron included a bar of cast iron 6½ in. long weighing 1 lb. 4 oz. as well as bars and sundry objects of wrought iron. Even at the rather primitive works at Hengistbury Head an irregular lump of white cast iron, about 2 lbs. in weight, was found, encrusted with slag.

In 1901 a statuette of cast iron was found in a cinder heap at Beaufort Park near Hastings : it was claimed to be Roman, but some authorities refused to accept it on the grounds that the Romans

could not make cast iron. In view of the above instances, there is now no need for scepticism.

It may seem curious that iron and lead should be worked near Stratford-on-Avon far from the mining centres of Mendip, Shelve or Derbyshire in one case and the Forest of Dean in the other. Probably it was more economical to take the ores or metals to a locality that provided good water-carriage facilities combined with the abundant timber for charcoal of the Forest of Arden.

GOLD

Gold was certainly worked in Britain at least as early as the Bronze Age, even if not in Neolithic times as in Brittany, but no traces, other than the fabricated objects, can be recognised. Workings would be alluvial and either on a small scale like those of the present century near Leadhills in Scotland or incidental to stream works for tin. When, however, we come to Roman times, one gold mine in solid rock is known : it is at Dolaucothy in the parish of Cynwyl Caeo, Carmarthenshire : it is also known as Gogofau. The country rock is Ordovician, with a number of quartz veins ; visible gold has been found, though rarely, in the quartz. There are several open-cast works on the veins from which the ore has been followed by adits for a distance of 170ft. The adits are 6 to 7½ft. high and 3 to 6ft. wide. Roman remains found are dateable from about A.D. 80 to 140. It is probable, though no evidence survives, that the mines were in existence in pre-Roman times. Many querns and crushing stones for pounding the quartz occur, which was then washed to extract the gold ; some of the milling stones have hollows in all four sides. The neighbouring village of Pumpsant is said to derive its name from one of these stones ; five hollows were supposed to be the impressions of the heads of five young saints, who used it as a pillow when benighted on a pilgrimage to the shrine of St. David. They were carried off to the interior of the hills by a sorcerer and will, on some happy day in the future, be released, when they will immediately undertake the necessary task of reforming the Welsh !

For the washing, water was brought by an artificial channel, mostly cut in solid rock, from the river Cothi, which was dammed for the purpose at a point seven miles from the mines. The channel is 2½ to 4½ft. wide and 1½ft. deep. Near the mines it opens into a reservoir and two tanks, regarded by O. Davies as pit-head baths. Several gold ornaments were found, including pendants, wheel amulets of a type well known in Gaul and Britain, a snake armlet and part of another with the eyes hollowed to receive gems or paste ; the collection is described by Wheeler as the finest of its kind from any Romano-British site ; I shall speak of these gems on a later occasion.

About a dozen years ago the mine was reopened and fortunately

Prof. Oliver Davies was able to study the Roman remains (see Bibliography). His results show that Dolaucothy is not only the finest Roman mine in Britain, but ranks among the most important in Europe. Smyth's account is accurate as far as it goes : his lower adit was adapted for both haulage and drainage ; it is 7ft. 6in. high with a maximum width of 5ft. 9in. ; a pathway along one side was paved to avoid the water. A stope 80ft. below this level has now been found, which obviously required artificial drainage. Professor Davies found and identified part of a Roman water-wheel built of wood : the diameter would have been 13 to 14ft., much the same as the well-preserved wheels from Rio Tinto. Such wheels were probably fitted with pots or leather buckets which have not survived at Dolaucothy ; one at Rio Tinto had 24 pots, one at the end of each spoke.

On the gallery walls the marks of gads are conspicuous, but in some parts evidence of the use of fire-setting survives. Objects found include a heavy iron hammer, numerous mill-stones, parts of a wooden panning cradle, pit-props, etc. In Davies' opinion this well-developed mine was a state enterprise.

CONCLUSION

We have seen that during the Roman period there is abundant direct evidence that all the economic metal ores of Britain (with such obvious exceptions as Wolfram) were being mined. Evidence of pre-Roman mining is usually less direct, but hardly less certain. During the period of the conquest such activities were, naturally, disturbed ; but in the third and fourth centuries, "as in the time of Cunobelinus," to quote from Collingwood, "the imports that Britain required to maintain the standard of life which she set herself were only a marginal fraction of all that she consumed."

With the end of Roman rule the standard fell, but some mining activity lingered on among the native Britons : as late as A.D. 600 a ship came to Cornwall with a cargo of grain and almost certainly returned with tin and copper. The incoming Anglo-Saxon peoples were neither miners nor metallurgists : in the tenth century copper, tin and brass are included in a list of imports in the Colloquy of Archbishop Alfric (died 1006), published by T. Wright in his "Volume of Vocabularies." So with the passing of the Roman occupation and influence the history of "Practical Geology in Early Britain" comes to an end.

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